UNIVERSITY OF ALBERTA

SEDIMENTOLOGY AND STRATIGRAPHY OF THE ALEXANDRA FORMATION HAY RIVER, NORTHWEST TERRITORIES

by

JONATHAN M. BELLOW

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

DEPARTMENT OF GEOLOGY

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled SEDIMENTOLOGY AND STRATIGRAPHY OF THE ALEXANDRA MEMBER, HAY RIVER, N.W.T. submitted by JONATHAN M. BELLOW in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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May 28, 1993

Dedicated to my parents;

to my Father for his support in acting as my "Second Supervisor"

and to my Mother for her continuous encouragement.

Abstract

The Late Devonian Alexandra Formation is a flat lying succession of limestones that outcrop in the Hay River region, Northwest Territories.

The Alexandra Formation consists of reefal, lagoonal, and tidal flat facies. Throughout the area, the lower part of the formation is formed of the coral, stromatoporoid floatstone-framestone facies and crinoid, brachiopod nodular floatstone facies. The upper part of the formation is formed mainly of cylindrical stromatoporoid floatstone- rudstones, thick tabular stromatoporoid framestones, *Amphipora* floatstone-rudstones, and algal laminated mudstones. Lagoonal and supratidal facies at Alexandra Falls interdigitate laterally into reef and forereef facies to the northeast. Collections from eight outcrops and cores from five wells allows for an areal evaluation of a reefal regieme that has suffered little dolomitization and minor tectonic disturbance.

Limestones in the lower part of the Alexandra Formation originated on a shallow ramp. During subsequent progradation, reef development produced a rimmed bank with more complex facies controlled by energy levels. The lower foreslope setting was characterized by low energy conditions whereas the upper foreslope was influenced by moderate to high energy conditions. High energy conditions on the reef crest gave rise to thick tabular stromatoporoid framestones and oncolitic floatstone-rudstones. The backreef lagoon was characterized by low energy conditions that favoured the growth of cylindrical stromatoporoid floatstones-rudstones, *Amphipora* floatstones-rudstones, and supratidal algal mats.

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CHAPTER 1

INTRODUCTION

Historical Studies of Devonian Reefs

Western Canadian Devonian carbonate buildups have been extensively studied since Imperial Oil discovered oil in a Late Devonian Leduc reef in 1947. Subsequent discovery of significant oil and gas in Middle and Late Devonian reefs led to extensive studies of these reefs (Klovan, 1964; Murray, 1966; Jamieson, 1967; Leavitt, 1968, Fischbuch, 1968; Jenik and Lerbekmo, 1968; Embry and Klovan, 1972; McGillivery and Mountjoy, 1975; Mountjoy and Jull, 1978; Wendte and Stoakes, 1982; Muir *et al.*, 1984; Machel, 1983, 1984; Walls, 1983; Geldsetzer *et al.*, 1988; Walls and Burrows, 1990). Similar studies have been published on the Devonian reefs of Australia (e.g., Playford, 1967, 1969, 1980, 1981, 1984) and Europe (e.g., Burchette, 1981; Tsien, 1977; Krebs and Mountjoy, 1972). As more of these carbonate complexes were studied, it became apparent that they all possessed a similar suite of depositional environments. Furthermore, some of these studies showed that most Devonian reefs have a distinct zonation of frame building organisms that were controlled by energy levels, sedimentation rates, and light and salinity conditions (Noble, 1970; Kobluk, 1975; Stearn, 1975, 1982; James, 1983). Many organisms inhabited specific environments.

Previous studies of Devonian reefs in Western Canada are either buildups in the subsurface, with widely spaced core information, or extensively dolomitized and tectonically disturbed exposures in the Rocky Mountains. The present study involves outcrop and core information from an undeformed Late Devonian carbonate buildup that has not been significantly dolomitized. Outcrop offers significant advantages over subsurface studies in that continuous exposure allows lateral environmental changes to be more readily observed than in core. The lack of significant tectonic disturbance allows the environments to be interpreted without structural complications.

Geographic Setting

The study area is located in the Great Slave Lake-Hay River region, Northwest Territories (Fig. 1). Outcrops pertinent to this study are located between 60° 30' N and 60° 52' N and 116° 00' W and 116° 40' W, and follow an arcuate trend, along Hay River from Alexandra Falls to Enterprise before swinging northwest along a limestone escarpment to Heart Lake. This escarpment, which is the principle topographic feature of the area, is covered by recent glacial sediments just west of Enterprise before gradually increasing in height westward, reaching 24 m of rock exposure at Heart Lake (Fig. 1). The average height of the escarpment is approximately 15 m (50 ft). The escarpment, which is irregular in plan, but roughly parallel to regional strike (Jamieson, 1967, 1969), represents the most continuous outcrop of strata. In some areas, a fault scarp may control the position of the escarpment suggesting that it may be of tectonic origin (Jamieson, 1967). The rest of the area is covered by muskeg and boreal forest that is drained by several streams and rivers that flow into the Mackenzie River. These streams and rivers cut through the strata with the result that outcrops are commonly located at waterfalls. The largest of these rivers, the Hay River, cuts through almost 30 m of section. Glacially polished outcrop surfaces that occur throughout the area offer no vertical relief.

During Late Devonian time the Hay River region occupied an equatorial position (Scotese and Morrow, 1990). The warm, shallow sea that covered the area, promoted widespread carbonate deposition. The absence of major regional tectonic activity has preserved the low angle of dip. The Tathlina Arch, which significantly affected the distribution of the underlying Middle Devonian deposits, did not influence Upper Devonian sedimentation. Upper Devonian strata dip gently to the southwest from the region of the Precambrian Shield east of Great Slave Lake (McLean *et al.*, 1987). Several small normal faults with a northeast trend cut the Upper Devonian strata. These orientations are similar to larger regional faults that occur to the south and east of Great Slave Lake (Douglas, 1959, 1974).

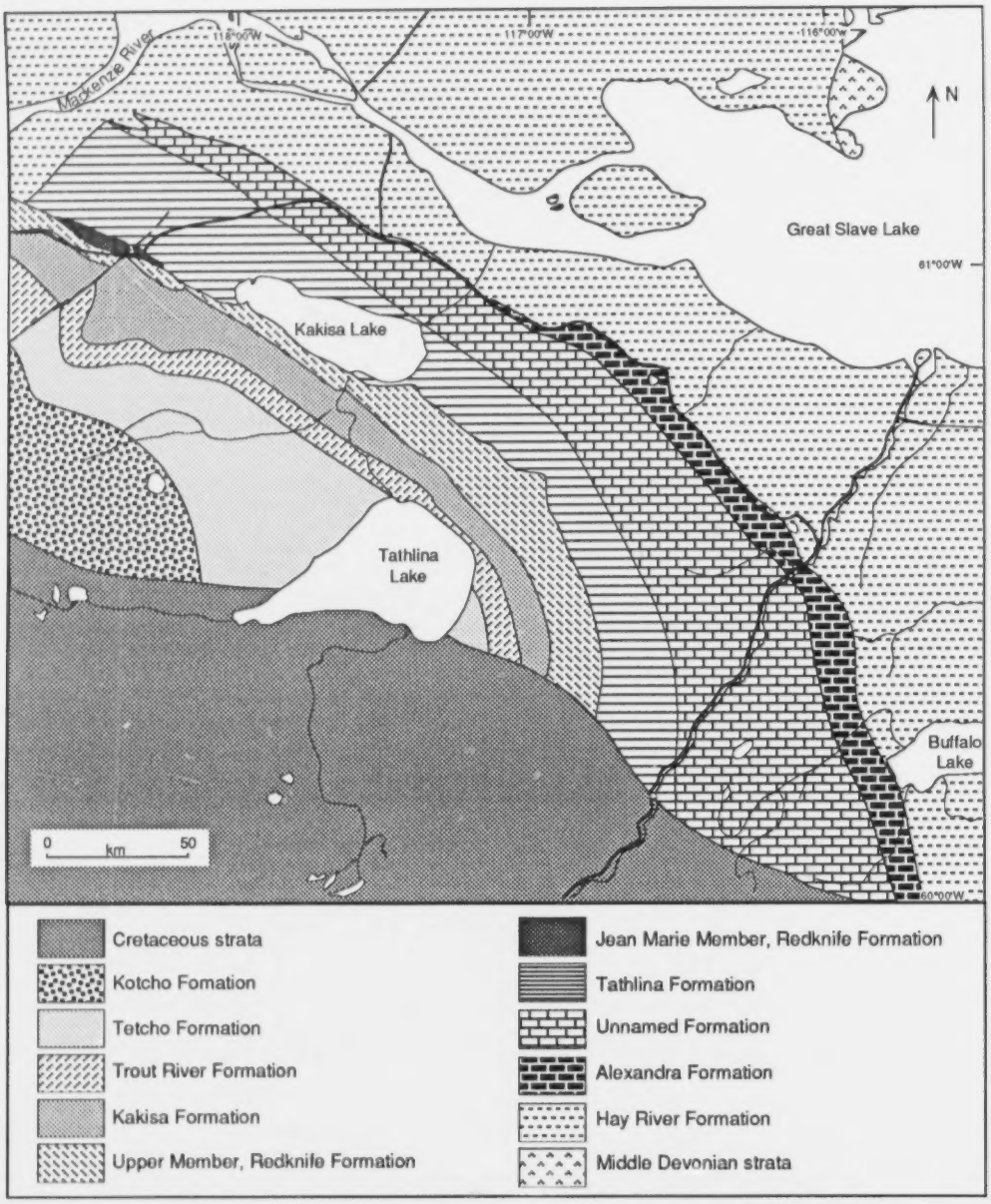


Figure 1. Map showing distribution of strata in the study area (modified after McLean *et al.*, 1987). Refer to fig. 6 for outcrop and well locations.

STRATIGRAPHIC FRAMEWORK (FIG. 2)

McConnell (1891) was the first to describe the Devonian limestones and shales that outcrop along the Hay River. Later, Cameron (1917, 1918, 1922) divided these strata into the Simpson Shales, Hay River Shales, and Hay River Limestones. The Simpson Shales, which encompassed 45 m (148 ft) of shale exposed around Fort Simpson, were considered older than the Hay River Shales. The overlying Hay River Shales consist of 122 metres (400 feet) of bluish-green shales with beds of fossil limestones and ripple marked sandstones. The Hay River Limestones, which are 90 m thick (296 ft), overlie the Hay River Shales with the contact at the base of Louise falls. Whittaker (1922) correlated the Hay River Limestones with similar limestones exposed along the Trout, Bouvier, Kakisa, and Jean Marie rivers. Basset and Stout (1968) erected the Hay River Formation to include the shale and limestones between the Slave Point Formation and the sandstones exposed at the base of Alexandra Falls. They also correlated the Hay River Formation into the Alberta subsurface using brachiopod assemblages. Fossil evidence suggested that the entire sequence was Upper Devonian (Cameron, 1922). This age was confirmed by subsequent paleontological work, most notably by Smith (1945) who described the coral fauna.

Crickmay (1952, 1953, 1957) further divided the lithologic units. The lowest shales exposed along the Hay River were assigned to the Simpson Formation because they were considered similar to the shales exposed around Fort Simpson. The Hay River Formation was restricted to Cameron's (1918) original definition of the Hay River Shales. Defined in that manner, the Hay River Formation encompasses 161.5 m (530 ft) of strata from the lowest shell bed exposed in the Hay River valley to the uppermost shale bed below Louise Falls. The 86 m (285 ft) of strata exposed at Alexandra and Louise falls, comprising the lower part of the Hay River Limestones as defined by Cameron (1918, 1922) were assigned to the Alexandra Formation (Crickmay, 1953). The 98 m (321 ft) of limestone above the Alexandra Formation were assigned to the Grumbler Formation, replacing the upper part of Cameron's Hay River Limestone. Crickmay (1957) relegated the Alexandra

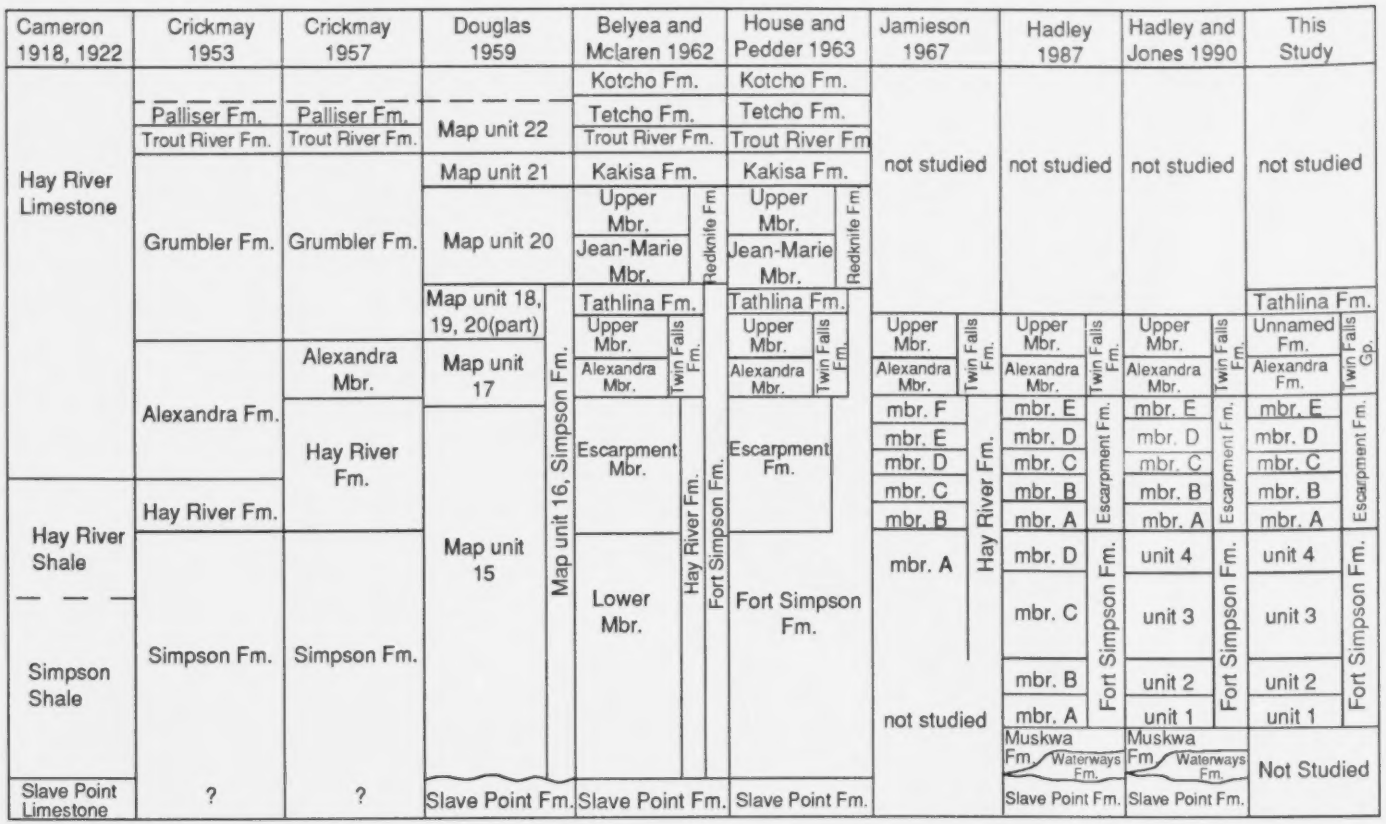


Figure 2. Historical stratigraphic nomenclature chart of the Late Devonian strata in the study area.

Formation to a member of the Twin Falls Formation and modified the definition to include all rocks exposed at Alexandra Falls except for the basal six feet of siltstone exposed at the base of the falls. The Alexandra Member thus defined, was 41 m (136 ft) thick. Douglas (1959, 1974) published a map showing his map unit 17 (which he considered to be equivalent to the Alexandra Formation) to be 43 m (141 ft) thick because he included 3.6 m (12 ft) of underlying beds that Crickmay (1957) assigned to the Hay River Formation. Strata previously assigned to the Simpson Formation were reassigned to the Fort Simpson Formation because the definition of the Simpson Formation was confusing (Douglas and Norris, 1961).

Belyea and McLaren (1962) further modified the stratigraphy of the region by elevating the Grumbler Formation to group status, so that it included all Frasnian strata above the Hay River Formation. They divided the Hay River Limestone, as defined by Cameron (1918, 1922), into the Tathlina and Twin Falls formations. The Twin Falls Formation was divided into the Alexandra Member and an unnamed Upper Member. The Alexandra Member, which is 31 m (100 ft) thick and corresponds to Crickmay's (1957) definition of the Alexandra Formation, excluding the upper 11 m (36 ft). These upper 11 metres of strata were placed in the Upper Member of the Twin Falls Formation. The Alexandra Formation (Crickmay, 1957) was therefore restricted to a local facies at the base of the Twin Falls Formation and relegated to member status. Belyea and McLaren (1962) designated a type section at Alexandra Falls and a supplementary reference section in the Murphy Canada Alexandra Falls No. 2.

In the subsurface, Belyea and McLaren (1962) showed that the Twin Falls Formation follows an arcuate trend from Kakisa River north of Tathlina Lake to the Hay River where it crosses into Alberta. From there it extends southeasterly to become part of the Grosmont Formation in the Red Earth region. To the west, a lateral facies transition occurs with the Fort Simpson Shales.

Belyea and McLaren (1962) divided the Hay River Formation into the Escarpment Member and an unnamed Lower Member. The Escarpment Member, which is 108 m (355 ft) thick, was correlated with limestone beds along the escarpment, near Escarpment Lake. The lower member is 120 m (393 ft) thick. House and Pedder (1963) abandoned the Hay River Formation by elevating the Escarpment Member to formation status and referring all lower shales to the Fort Simpson Formation.

Jamieson (1967) extensively modified the stratigraphic nomenclature of the area by dividing the Hay River Formation into Member 1, Member 2, Sandwich, Enterprise, Louise Falls, and Lookout members. She measured a total thickness of 136 m (455 ft). The lower contact with the Fort Simpson Formation was not studied and remained unchanged from that defined by House and Pedder (1963). Jamieson (1967) showed that the Alexandra Member (Twin Falls Formation), with its type section at Alexandra Falls, was 24 m (80 ft) thick. The discrepancy between this thickness and that given by Belyea and McLaren (1962) reflects the change in the position of the lower contact of the Alexandra Member with the Escarpment Formation to a sharp surface between the lowest coral bed and the dolomitic siltstones of the Lookout Member (Escarpment Formation). The contact with the upper member of the Twin Falls Formation remained unchanged from that of Belyea and McLaren (1962). Jamieson (1967) also suggested that some of Belyea and McLaren's (1962) correlations needed revision. For example, Belyea and McLaren (1962) correlated the limestone biostromes outcropping along the escarpment west at Heart Lake with the limestones of the Escarpment Formation at Louise Falls. Jamieson (1967), however, showed that the Louise Falls outcrops are older than the Heart Lake rocks (which she placed in the Alexandra Member) and therefore suggested that the Escarpment Formation be dropped. Williams (1977) agreed with this conclusion but Douglas (1959, 1974) used the Escarpment Member for the single bed of limestone that forms the lip of Louise Falls. McLean and Pedder (1987) and McLean *et al.* (1987) used the terminology

proposed by Belyea and McLaren (1962) coupled with the Hay River Formation divisions of Jamieson (1967).

Hadley (1987) and Hadley and Jones (1990) redefined the nomenclature of the strata underlying the Alexandra Member. The Hay River Formation was abandoned in favor of dividing the strata into the Fort Simpson and Escarpment formations. The boundary between the Alexandra Member and the Escarpment Formation was placed at the base of a bioturbated, dolomitic siltstone. The Escarpment Formation was divided into members A to E. The Twin Falls Formation remained unchanged from that of Jamieson (1967).

The stratigraphic nomenclature used for the present study follows that of Hadley and Jones (1990). The lower contact of the Alexandra Formation with the Escarpment Formation remains at the dolomitic siltstone because it is readily evident in core and outcrop (Plate 1). The upper contact with the Upper Member (Twin Falls Formation) is placed at the bottom of a 1.0 m thick shale bed at the type section at Alexandra Falls. This is the only exposure of the upper contact and must be interpreted with some caution.

AGE OF THE ALEXANDRA FORMATION

Conodonts from the strata of the Hay River-Trout River area shows that the Alexandra Formation is Upper Devonian (Klapper and Lane, 1985). The entire Frasnian sequence is characterized by the *Polygnathus* biofacies. Local minor incursions of species of *Palmatolepis*, *Ancyrodella*, and *Ancyrognathus* that characterize Frasnian strata in other parts of the world *Palmatolepis* biofacies are found. The intercorrelation between these two biofacies in the Hay River region has not been fully resolved (Klapper and Lane, 1985).

The Hay River Formation of Klapper and Lane (1985) extends from the Middle or Upper *Asymmetricus* zone into the *A. triangularis* or Lower *gigas* zone. Part of the Alexandra Formation is of Lower *gigas* zone with the uppermost Fort Simpson Shale, Redknife and Kakisa formations being in the Upper *gigas* zone.

PLATE 1

(A) Alexandra Falls, N.W.T. Type section of the Alexandra Formation showing the contact between the dolomitic siltstone of the Escarpment Formation (arrow) and the basal stromatoporoid solitary coral floatstone facies of the Alexandra Formation.

(B) Twin Falls Creek, N.W.T. Contact (arrow) between the dolomitic siltstone of the Escarpment Formation and the basal stromatoporoid solitary coral floatstone facies of the Alexandra Formation, Upper Falls at Twin Falls Creek.

A

ALEXANDRA MEMBER OR ALEXANDRA FORMATION?

Confusion has arisen in the past because the strata exposed at Alexandra Falls have, in the past, been assigned at various times to the Alexandra Formation (Crickmay, 1957; Douglas, 1959) or the Alexandra Member of the Twin Falls Formation (Belyea and McLaren, 1962; Jamieson, 1967; Hadley, 1987; Hadley and Jones, 1990). The Alexandra Formation (Crickmay, 1957) included all rocks exposed at Alexandra Falls excluding the basal 2 m (6 feet) of siltstone. Limestones exposed in the lower part of the Trout River valley were also assigned to the Alexandra Formation (Crickmay, 1957). The Trout River rocks are now known to occupy a stratigraphic position at least 107 m (350 ft) higher than the strata exposed at Alexandra Falls (Belyea and McLaren, 1962). Those strata should have been assigned to the Grumbler Formation (Crickmay, 1957).

Conversely, Belyea and McLaren (1962) included the Alexandra Formation (Crickmay, 1957) as a member in the Twin Falls Formation. The exclusion of the Trout River strata from the Alexandra Formation (Crickmay, 1957) and the correlation of the biostrome at Heart Lake with the Escarpment Formation at Louise Falls (Belyea and McLaren, 1962) relegated the Alexandra Formation (Crickmay, 1957) to a local unit occurring at the base of the Twin Falls Formation (Belyea and McLaren, 1962).

Jamieson (1967) reinterpreted the stratigraphic correlations, suggesting that the limestones exposed at Heart Lake were younger than those at Louise Falls. The Heart Lake Biostrome was correlated with the strata at Alexandra Falls and placed in the Alexandra Member (Jamieson, 1967).

Several criteria must be satisfied in order to assign formation status to a rock unit. It should be a mappable unit with a distinct lithic character and possess some degree of lithic homogeneity when compared to adjacent units. The Alexandra Member is mappable in outcrop over a distance of 250 km (Fig. 1). In the subsurface, the Alexandra Member can be traced south into Alberta for an additional 200 km before it merges with the Grosmont Reef Complex west of Peace River (Fig. 3). The Alexandra Member is composed of

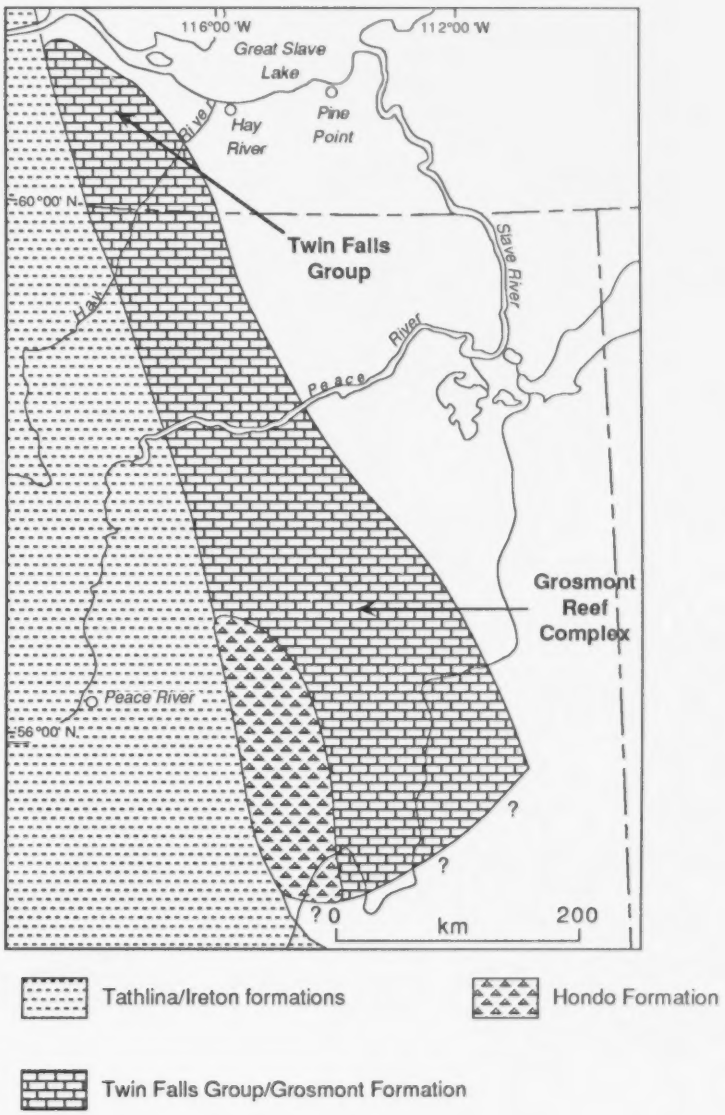


Figure 3. Map showing the subsurface continuation of the Alexandra Formation into Alberta as the Grosmont Reef Complex (modified after Williams, 1977).

lithologies that are distinct from the formations stratigraphically above and below (Fig. 4 and Fig. 5). This distinction is particularly evident in Union Alexandra Falls No. 1 where the Alexandra Member lithologies are in sharp contrast to the Upper Member and the Escarpment Formation (Fig. 5). In this study that the Alexandra Member meets the criteria of a formation and thus will be referred to as the Alexandra Formation (Twin Falls Group).

OBJECTIVES

The main objectives of the study are to:

1. Develop a better understanding of the facies distribution in the Alexandra Formation (Twin Falls Group) by combining outcrop data with subsurface core information,
2. Interpret the facies and examine the fossil zonation in the Alexandra Formation,
3. Map the distribution of facies in the Alexandra Formation,
4. Create a paleogeographic model of deposition using the facies and fossil zonation, and
5. Consider the stratigraphic status of the Alexandra Formation,

METHODS AND MATERIALS

Fieldwork was completed in the 1990 and 1991 field seasons. In August 1990, 165 m of diamond drill core from five boreholes were logged and sampled at Cominco's Pine Point mine site. Reconnaissance work of the outcrops was also completed. In 1991 eight outcrops located along the Mackenzie Highway south and west of Enterprise were sampled and measured (Fig. 6). The 184 core samples and 147 outcrop samples were chosen to ensure adequate representation of the facies.

All samples were slabbed with a diamond saw and polished or varnished to facilitate examination and photography. Sixty-four large thin sections (7.5 X 5.0 cm) were prepared and examined with a petrographic microscope. Samples were impregnated with blue epoxy before thin sectioning so that original porosity could be highlighted. Alizarin red S and potassium ferricyanide stains were applied to the thin sections and the slabs to permit

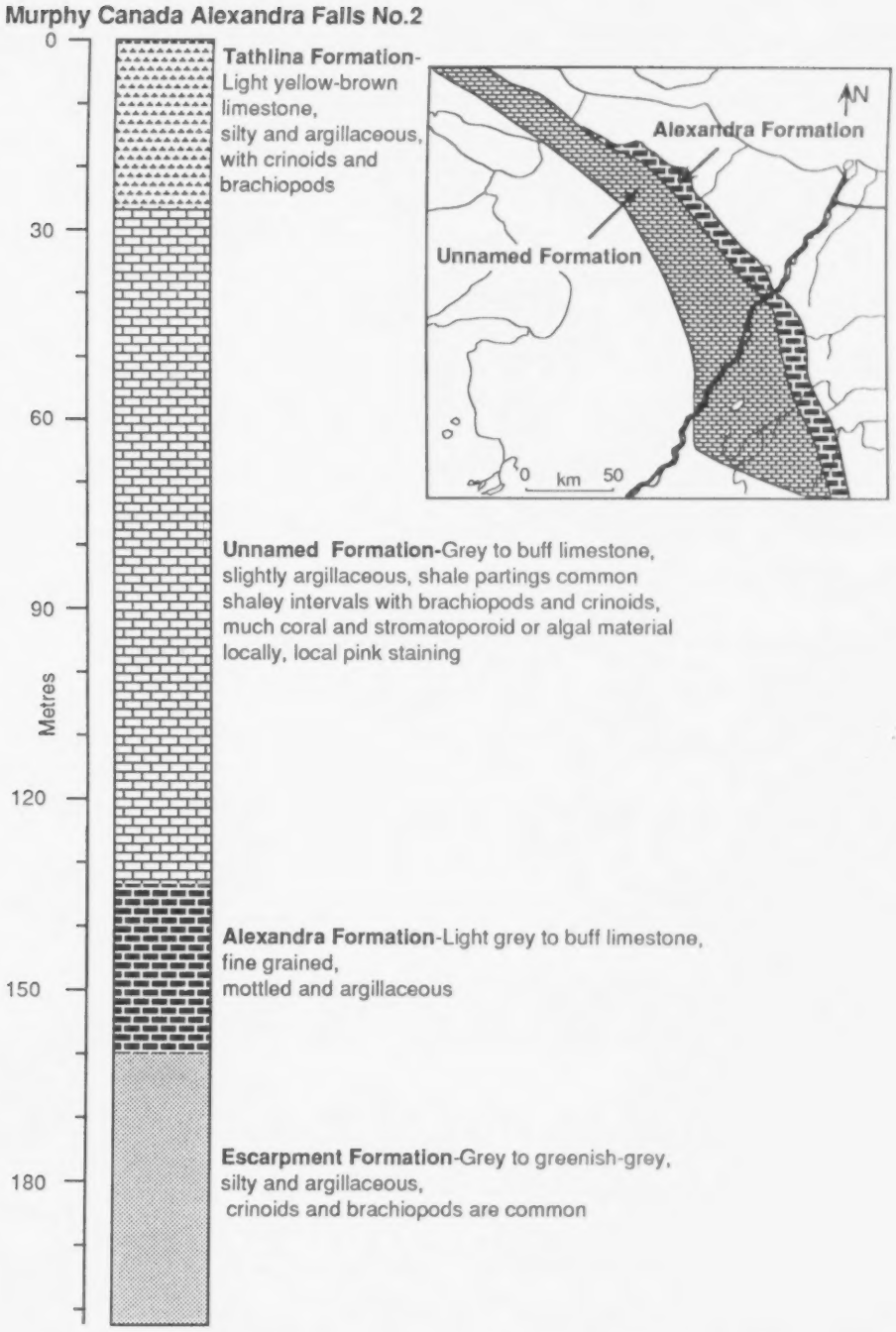
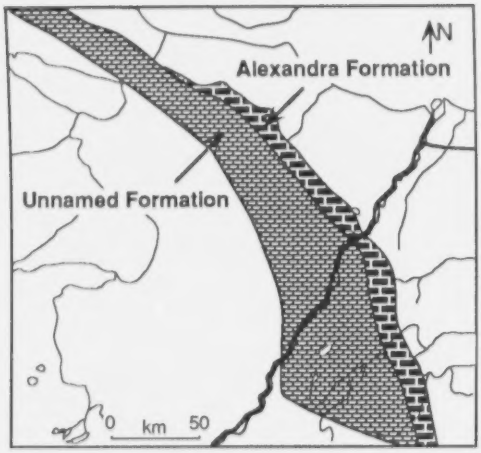


Figure 4. Lithology log from cuttings of Murphy Canada Alexandra Falls No. 2 showing the lithologies from the Alexandra Formation, Unnamed Formation and Escarpment Formation (modified after Belyea and McLaren, 1962). Map shows the extent to which the Alexandra Formation can be mapped in outcrop.



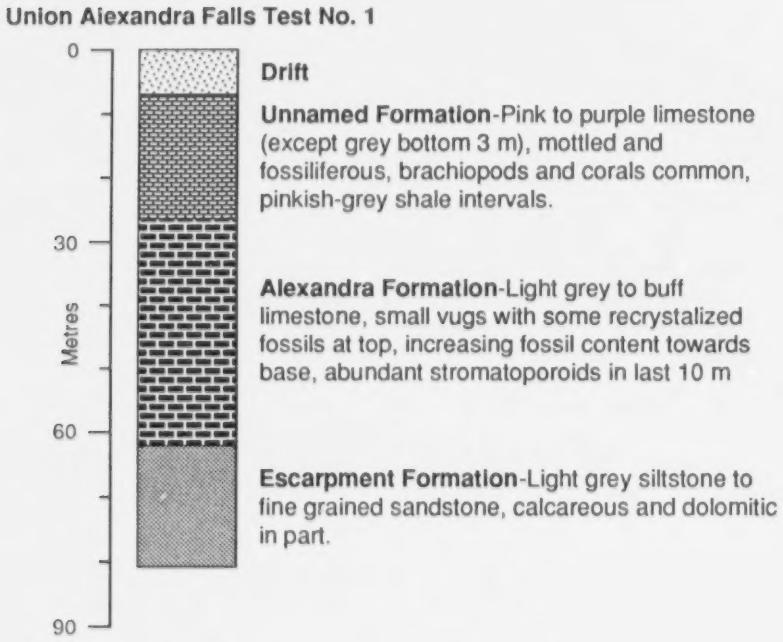

Union Alexandra Falls Test No. 1
0
30
60
90
Metres
Drift
Unnamed Formation-Pink to purple limestone (except grey bottom 3 m), mottled and fossiliferous, brachiopods and corals common, pinkish-grey shale intervals.
Alexandra Formation-Light grey to buff limestone, small vugs with some recrystalized fossils at top, increasing fossil content towards base, abundant stromatoporoids in last 10 m
Escarpment Formation-Light grey siltstone to fine grained sandstone, calcareous and dolomitic in part.

Figure 5. Lithology from cutting of Union Alexandra Falls No. 1 showing the distinctive formation boundaries present in this well (modified after Belyea and McLaren, 1962).

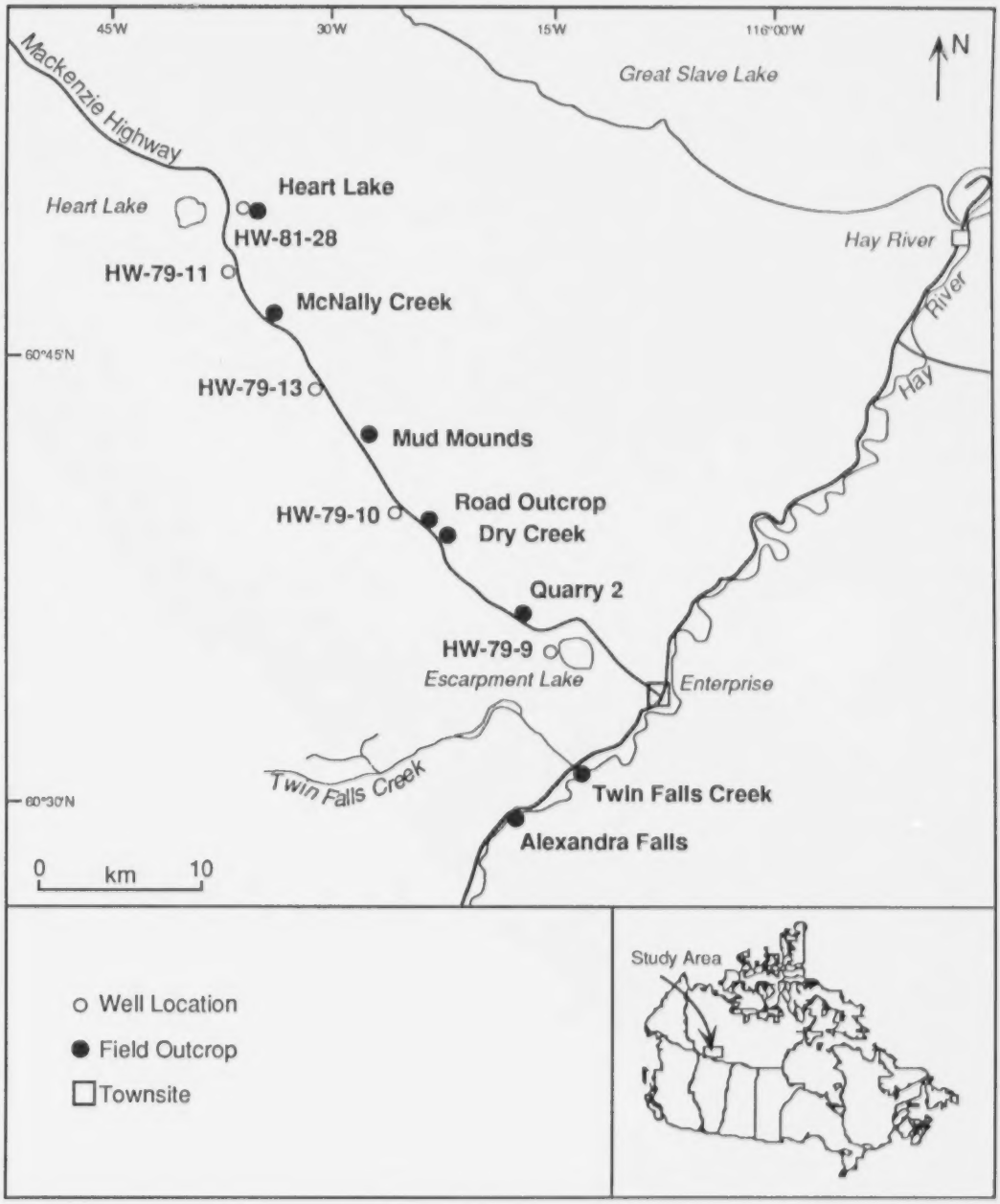


Figure 6. Study area map showing Alexandra Formation outcrop and core locations. Refer to figure 1 for outcrop geology (modified after Hadley, 1987).

identification of calcite, ferroan calcite, dolomite, and ferroan dolomite. Such staining was completed according to the techniques outlined by Dickson (1965).

CHAPTER 2

ROCK CLASSIFICATION AND FACIES DESCRIPTIONS

Introduction

Limestones, dolomitic limestones, shales, and calcareous siltstones are common throughout the study area. The upper part of the Alexandra Formation and the unnamed formation (Twin Falls Group) are dominantly limestones and dolomitic limestones with little clay or silt in the matrix. The lower part of the Alexandra Formation and the underlying Escarpment Formation are dominantly argillaceous limestone, shale, calcareous and dolomitic siltstones, and sandstones. The common occurrences of mixed composition mixed rocks required a classification that could be easily modified.

The Embry and Klovan (1972) modification of the Dunham (1962) classification was used to name the facies of the Alexandra Formation (Fig. 7). The basic textural term is used with modifiers describing the principal fossils (or other allochems) present. Oncolites, which occur in the upper part of the Alexandra Formation is used in the sense of Tucker and Wright (1983). As dolomitization has not severely altered the depositional texture of the rocks, a separate classification for dolomites is not needed. Where necessary, the prefix "dolomitic" has been added to the basic rock name.

Shale refers to a clay rich, fissile to laminated rock, with variable silt and carbonate content, following the definition of Folk (1968) and Pettijohn (1975). Modifiers such as calcareous or dolomitic are employed where necessary. Siltstone is used when quartz grains of silt size form more than 30 % of the rock.

FACIES DESCRIPTIONS

Criteria for Establishing Facies

Ten facies are recognized in the Alexandra Formation. Diagenetic changes, which are noted in the facies descriptions were not a major factor in delineating the facies. The

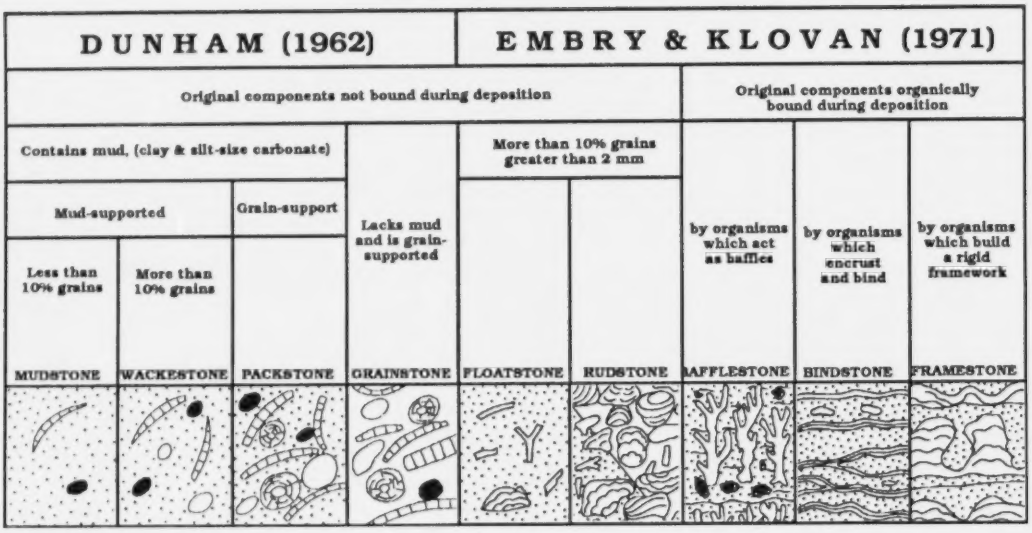


Figure 7. The (Embry and Klovan, 1971) modified (Dunham, 1962) classification of carbonate rocks.

dominant type of fossil (or other allochem) and depositional texture are the principal factors in recognizing the facies present.

The facies were delineated in order to map the distribution of the major depositional environments in the Alexandra Formation. Most facies could have been divided into sub-facies (or even microfacies) based on variations in fossil content. This was not necessary for the purposes of this study as the depositional environments are large scale features. Subdividing the facies into smaller units would have increased the complexity of the facies correlations and masked the distribution of the larger scale depositional environments.

1. Tabular Stromatoporoid Framestone Facies

Occurrence

The vertical escarpment at Heart Lake (Fig. 6) offers a superb exposure of this facies where continuous lateral exposure over several hundred metres allows description of all its characteristic features. At McNally Creek there is excellent vertical but poor lateral exposure of the facies. This facies also occurs in the cores from HW-81-28, HW-79-11, HW-79-13, and HW-79-10.

Description

This is a resistant limestone that weathers to a medium grey colour. The allochems have a buff colour whereas the matrix is usually slightly darker. Tabular stromatoporoids are the dominant fossil component. These dish-shaped, concave-downwards colonies are 2 mm to 40 cm thick and 20 to 75 cm in diameter. They are divided into the thick tabular stromatoporoids (> 2 cm thick) and thin tabular stromatoporoids (< 2 cm thick). The thick tabular stromatoporoids, which are the frame-building component of the biostromes, are more common than the thin tabular stromatoporoids. The thick tabular stromatoporoids occur as overlapping colonies that give the outcrops a stratified appearance (Plate 2A, 2B, 2C). Crinoids, brachiopods, and gastropods are consistently present in minor amounts throughout the facies. Other fossils, which include cylindrical stromatoporoids, colonial corals, *Thamnopora*, solitary corals, and *Renalcis* (Plate 2D), are rare to common.

PLATE 2

A) Tabular stromatoporoid framestone facies. Outcrop at Heart Lake with large subspherical stromatoporoid colonies in the thick tabular stromatoporoid facies.

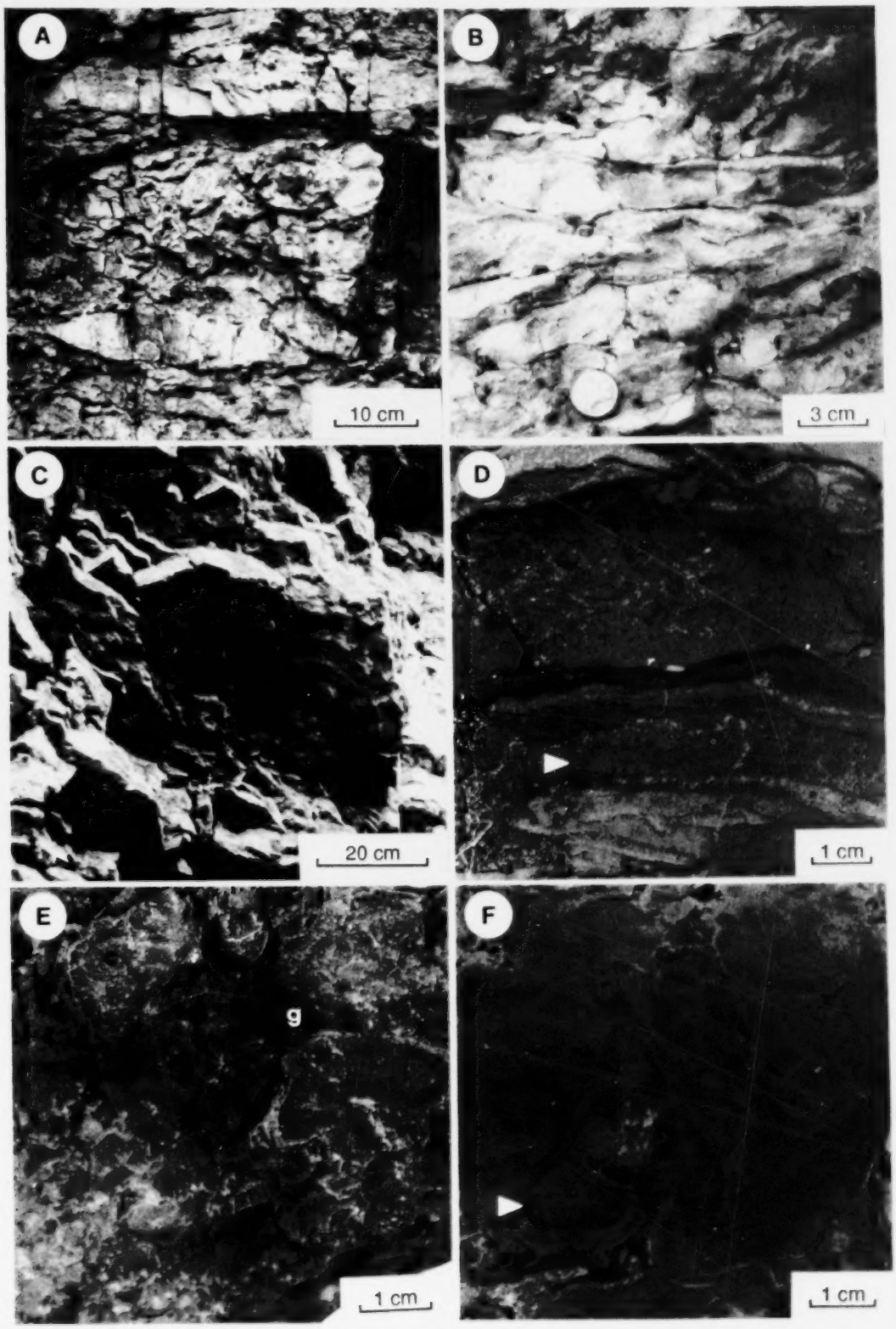
B) Tabular stromatoporoid framestone facies. Outcrop at Heart Lake showing "bedded" nature of this facies caused by the horizontal to sub - horizontal attitude of the tabular stromatoporoids.

C) Tabular stromatoporoid framestone facies. Outcrop at Heart Lake showing underside of a thick, round tabular stromatoporoid.

D) Tabular stromatoporoid framestone facies. Polished slab from Heart Lake showing thinner tabular stromatoporoids in a skeletal packstone matrix. Note *Renalcis* algae (arrow) at bottom of photograph.

E) Tabular stromatoporoid framestone facies. Skeletal gravel from Heart Lake showing clasts of skeletal debris (mainly tabular and cylindrical stromatoporoids) and green shale in the inter - particle voids.

F) Cylindrical stromatoporoid floatstone facies. Polished slab from Quarry 2 showing cylindrical stromatoporoids (arrow) in a skeletal wackestone matrix.


A
10 cm
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3 cm
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1 cm
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Most tabular stromatoporoids are in growth position. They occur as overlapping stacked colonies with most individual colonies whole and unabraded. Fracturing of the stromatoporoid colonies resulted from post-depositional compaction. The thick stromatoporoids grew by encrusting the firm substrate provided by the previous stromatoporoid generations. Less commonly, the thin stromatoporoids grew on irregularly shaped, abraded fossil fragments such as colonial corals. Colonial corals are the only other organism commonly found in growth position. Elsewhere, the thin tabular stromatoporoids, colonial and solitary corals are slightly abraded, fractured, or overturned. Most of the other fossils have been transported to some degree. Locally, severely abraded and fragmented cylindrical stromatoporoids and *Thamnopora* occur as gravel - sized debris in association with fragmented tabular stromatoporoid and colonial coral fragments (Plate 2E). The gravels occur between regions of *in situ* thick tabular stromatoporoid growth. Whole and disarticulated brachiopods, whole gastropods, and partially to completely disarticulated crinoid stalks also occur in the gravel.

The packstone to grainstone matrix consists of skeletal fragments, 0.2 to 2 mm in size, (mainly brachiopod fragments, crinoid ossicles, gastropod fragments, ostracods, and indeterminate skeletal material), peloids (?), and lime mud.

Locally, the mud is partially to completely dolomitized. The dolomite occurs as subhedral to euhedral, zoned dolomite rhombs up to 0.25 mm long. Calcite spar cement occurs in shelter porosity, fractures, and fills intraskeletal cavities in the stromatoporoids and corals. High amplitude (2 to 7 cm) stylolites are common. Green shale partings up to 2 cm thick occur locally.

Comparison

Facies dominated by tabular stromatoporoids are known from several Devonian localities in Western Canada. Murray (1966) described a 'well banded facies' dominated by tabular stromatoporoids in the Swan Hills reef. Those thick tabular stromatoporoids were considered transitional between thin tabular and massive stromatoporoid growth

forms. The tabular stromatoporoid facies was placed in the lower part of the bank margin, where energy conditions were high but less than that on the reef crest. Alternating *in situ* thick tabular, encrusting stromatoporoids and gravel sized rubble occur in the Judy Creek and Kee Scarp reefs (Wendte and Stoakes, 1982; Muir *et al.*, 1984). These facies were placed in the high energy, wave swept reef margin of the upper foreslope. Vopni and Lerbekmo (1972) placed tabular stromatoporoids that occur in association with massive forms in the Horn Plateau reef, in the zone of highest energy, on the reef crest margin. An *in situ* tabular stromatoporoid subfacies with stromatoporoids 5 to 15 cm high and 10 to 25 cm diameter was described from the Miette reef margin (Noble, 1970). Machel (1990) considered the tabular stromatoporoids to be dominant in the reef core immediately behind the reef crest.

Other studies have placed tabular stromatoporoids in different environmental positions. Embry and Klovan (1972), for example, placed tabular stromatoporoids below normal wave base but still above storm wave base. Similarly, a mud supported tabular stromatoporoid facies in the Golden Spike Reef was considered indicative of forereef facies (McGillivray, 1977). Conversely thin tabular stromatoporoid dominated facies have also been placed in basinal bank position (Davies and Tooth, 1987).

2. Cylindrical Stromatoporoid Floatstone-Rudstone Facies

Occurrence

This facies is best preserved in core from HW-79-9, HW-79-10, HW-79-11, and HW-79-13. Outcrop exposure of this facies is limited to small outcrops at Twin Falls Creek, Quarry 2, and the Road Outcrop (Fig. 6).

Description

This buff to tan coloured limestone is dominated by cylindrical stromatoporoids (5 mm - 2.5 cm in diameter) that commonly have an irregular micritic coating (Plate 2F). *Thamnopora*, colonial and solitary corals, thin tabular stromatoporoids (2 mm to 10 mm

thick and 10 to 20 cm diameter), and *Amphipora* (1 mm to 5 mm diameter) occur in lesser numbers. Brachiopods, gastropods, and crinoids form a minor part of the rock.

Most fossil material in this facies has undergone some transportation. The cylindrical stromatoporoid branches have been knocked over, broken, and abraded. The *Amphipora*, colonial corals, and *Thamnopora* are in much the same condition as the cylindrical stromatoporoids. Locally, however, some tabular stromatoporoids occur in growth position. This is suggested by the occurrence of complex wispy shapes that would have broken with even minor transport. The crinoids, brachiopods, and gastropods occur as ossicles, disarticulated and broken shells, and whole shells respectively.

Inter-particle zones are cemented with spar calcite or filled with a skeletal wackestone to packstone matrix. In the former, a white to colourless calcite spar cement almost completely fills the pores between the cylindrical stromatoporoids. This calcite cement has only been found in core and is best represented in HW-79-10. Skeletal wackestone to packstone matrix fills the remainder of the pore space. The wackestone to grainstone matrix is composed of *Thamnopora* fragments, brachiopod shells, crinoid ossicles, and unidentifiable skeletal fragments.

The mud in the matrix is partly to completely replaced by subhedral to euhedral zoned dolomite rhombs up to 0.25 mm long. High amplitude stylolites (with amplitudes of 2 to 7 cm) are common. Green clay partings, up to 2 cm thick, occur locally.

Comparison

Past studies suggest that cylindrical stromatoporoids may have flourished in two distinct environments in Devonian reefs. Facies dominated by cylindrical stromatoporoids with lesser amounts of abraded stromatoporoid clasts, dendroid corals, and *Amphipora* occur in the middle foreslope deposits of the Kee Scarp and Judy Creek reefs (Muir *et al.*, 1984, Wendte and Stoakes, 1982). By comparison, the upper middle foreslope contains significantly greater amounts of cylindrical stromatoporoids with little micrite. The matrix of this upper foreslope deposit is a skeletal grainstone. The lower middle foreslope

contains, in addition to the cylindrical stromatoporoids, some thin tabular stromatoporoids in a mudstone to wackestone matrix, indicating lower energy conditions. The change in energy conditions from the lower energy lower middle foreslope to the higher energy upper middle foreslope was probably responsible for the change from matrix to cement filled pore spaces between the cylindrical stromatoporoids.

In the Swan Hills reefs, cylindrical stromatoporoids occur in the forereef and backreef environments (Fischbuch, 1968; Fischbuch and Havard, 1987). Kobluk (1975) and Machel (1990) also placed cylindrical stromatoporoid - dominated facies in both forereef and backreef positions. The fossil assemblage in both settings consists of fragmented, abraded cylindrical stromatoporoids that occur with dendroid corals, and thin tabular stromatoporoids. Calcite spar fills the inter-fossil porosity of the forereef deposits whereas the interstitial material of the backreef consists of a skeletal wackestone to packstone matrix.

3. *Amphipora* Floatstone-Rudstone Facies

Occurrence

Although best exposed at Alexandra Falls (Fig. 6), this facies also outcrops at Twin Falls Creek, Quarry 2, and the Road Outcrop. In core, this facies occurs in HW-79-9 (Fig. 6).

Description

Amphipora is the dominant fossil in this light brown floatstone to rudstone (Plate 3A). Cylindrical stromatoporoids (3 mm to 1.5 cm diameter), thin tabular stromatoporoids (2 to 10 mm thick, 3 to 15 cm diameter), *Thamnopora*, (1 to 3 cm long fragments) and solitary corals (5 to 10 mm diameter) occur in lesser numbers.

All fossil material shows evidence of transportation, with the *Amphipora*, *Thamnopora*, and cylindrical stromatoporoids being fragmented and abraded. The thin tabular stromatoporoids are broken, abraded, and occur with their long axes in variable orientations.

PLATE 3

(A) *Amphipora* floatstone to rudstone facies. Polished slab from Quarry 2 showing *Amphipora* in a skeletal wackestone matrix. Note high amplitude stylolites.

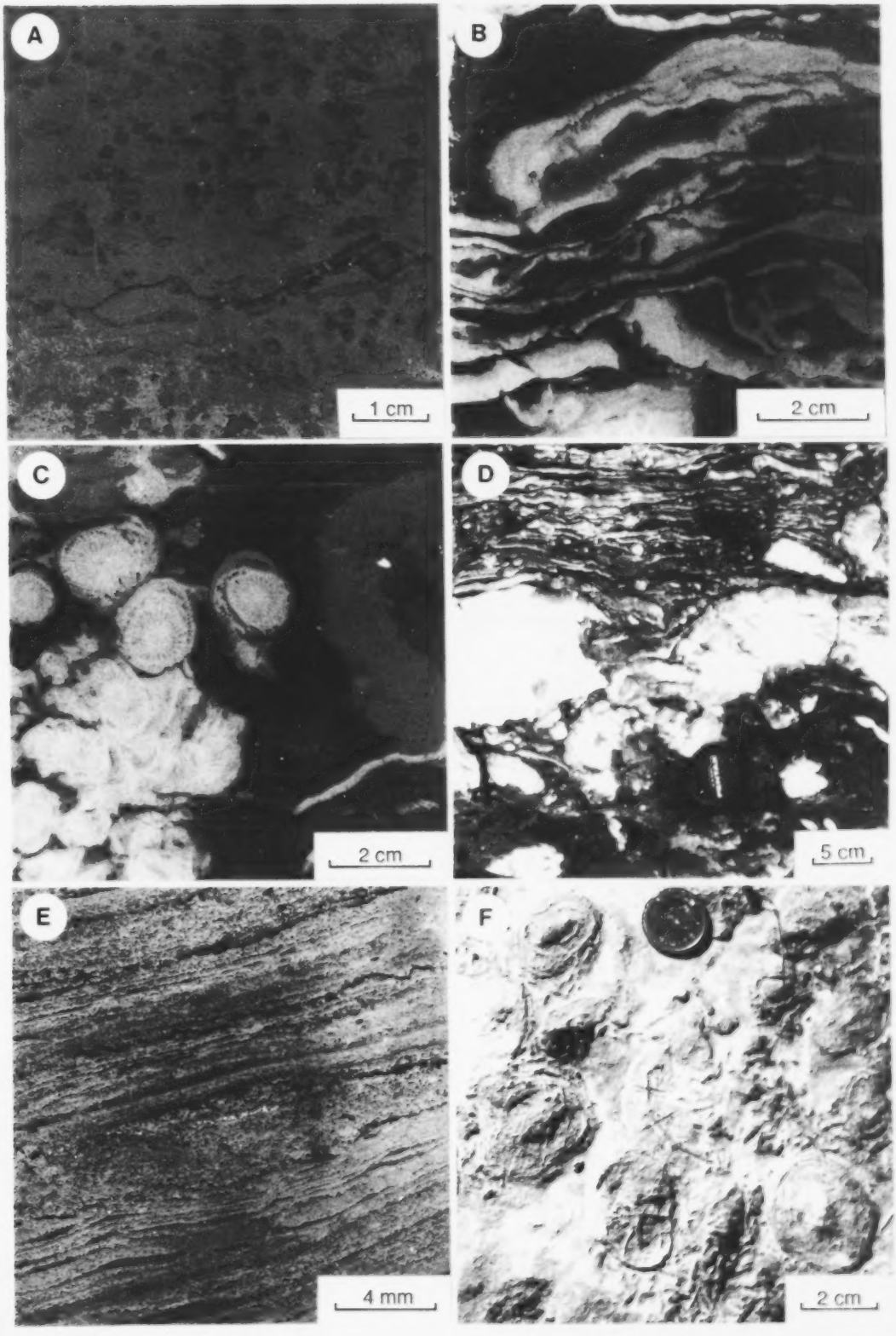
(B) Stromatoporoid coral floatstone to framestone facies. Polished slab from McNally Creek showing thin tabular stromatoporoids and dark argillaceous matrix typical of this facies.

(C) Stromatoporoid coral floatstone to framestone facies. Polished slab from the Dry Creek showing a colonial coral and thin tabular stromatoporoid.

(D) Stromatoporoid coral floatstone to framestone facies. Outcrop at Dry Creek showing framestone texture formed by thin tabular stromatoporoids and large colonial corals.

(E) Laminated mudstone facies. Negative thin section photograph showing the irregular (algal?) and micritic layers. 28.7 m above section base, Alexandra Falls.

(F) Oncolitic floatstone to rudstone facies. Oncolites differentially weathering out on surface outcrop.


A
1 cm
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2 cm
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2 cm
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5 cm
E
4 mm
F
2 cm

The matrix is a skeletal wackestone to packstone, consisting of brachiopod shells, gastropods, crinoid ossicles, and other indeterminate skeletal material. Most skeletal material is broken and abraded. Whole brachiopods and gastropods occur locally.

The mud component of the matrix is partly to completely dolomitized. Dolomite occurs as zoned subhedral to euhedral rhombs up to 0.25 mm long. Locally the *Amphipora* have been recrystallized. High amplitude (2 to 7 cm) stylolites, similar to those in the cylindrical stromatoporoid facies, also occur in this facies.

Comparison

Devonian fossil assemblages dominated by *Amphipora* may have inhabited sheltered, slightly restricted waters in the back reef lagoons (Murray, 1966; Fischbuch, 1968; Wendte and Stoakes, 1982; Muir *et al.*, 1984). The colour of the matrix may provide a general indication of the degree of restriction (i.e., lack of open seawater circulation) of the lagoon (Wendte and Stoakes, 1982). Generally, the darker the matrix, the more restricted the lagoon. For example, an *Amphipora* floatstone to rudstone with a light brown wackestone to packstone matrix occurs in the better circulated areas of the Kee Scarp and Judy Creek reefs (Wendte and Stoakes, 1982; Muir *et al.*, 1987). Darker brown, muddier sediments occurred in more restricted areas of the lagoon (Wendte and Stoakes, 1982; Muir *et al.*, 1984).

4. Stromatoporoid, Coral Floatstone-Framestone Facies

Occurrence

This facies is exposed in outcrop at Alexandra Falls, Twin Falls Creek, Dry Creek, and McNally Creek. In core, the facies occurs in HW-79-9, HW-79-10, HW-79-11, HW-79-13, and HW-81-28 (Fig. 6).

Description

The biota of this medium grey-green argillaceous floatstone is dominated by thin tabular stromatoporoids (4 to 10 mm thick, 2 to 15 cm long - Plate 3B), *Thamnopora* (branch fragments up to 3 cm long), and colonial corals (up to 40 cm in diameter - Plate

3C). Brachiopods, crinoids, and gastropods occur in lesser numbers. In most places, all fossils with the exception of some of the thin tabular stromatoporoids show evidence of transportation. The colonial coral heads are abraded and overturned whereas the *Thamnopora* branches are fragmented and abraded. Brachiopods occur as disarticulated and broken shell fragments. Locally, framestone textures (e.g., Dry Creek - Plate 3D) exist in which the thin tabular stromatoporoids and colonial corals form a rigid framework.

These fossils occur in an argillaceous skeletal lime wackestone matrix. The skeletal component of the matrix consists of fragmented and abraded brachiopods, echinoid plates, crinoid ossicles, and rare whole gastropod shells. A poorly developed nodular texture results from weathering of more argillaceous parts of the rock.

In the more carbonate rich areas, the mud is partially dolomitized with subhedral to euhedral dolomite rhombs. Horsetail stylolites (up to 3 cm thick) and green clay partings (1-5 mm thick) are common.

Comparison

Argillaceous carbonates with fossil assemblages dominated by branching corals, thin tabular stromatoporoids, and solitary corals are thought to occur on deeper water carbonate platforms. Locally, such platforms are the site of incipient reef growth. A thin tabular stromatoporoid, *Thamnopora*, and cylindrical stromatoporoid dominated floatstones (locally rudstones) occur in the platform deposits below the Gift Lake reef of the Slave Point Formation (Tooth and Davies, 1987). There is considerable lateral and vertical fossil zonation with the thinner tabular stromatoporoids on the leeward side of the platform and the thicker tabular stromatoporoids on the windward side. Similar platform facies with bulbous and cylindrical stromatoporoids, *Thamnopora*, crinoids and brachiopods also occur at other localities in the Slave Point Formation (Craig, 1987). Wendte and Stoakes (1984) described basal shoal limestones with cylindrical stromatoporoid, *Thamnopora*, and branching corals in a skeletal wackestone to packstone matrix from the Judy Creek reef. Similar deposits occur in the Kee Scarp reef platform (Muir *et al.*, 1984). Cylindrical

stromatoporoids, *Thamnopora*, and branching corals are delicate growth forms that could not have survived high energy environments. The presence of mud further supports a low energy depositional environment. Localities containing thicker tabular stromatoporoids would have been able to withstand higher energy conditions (Tooth and Davis, 1987). The higher energy deposits represent local platform highs on which reef development could occur.

5. Laminated Mudstone Facies

Occurrence

The laminated mudstone facies only occurs in the Alexandra Falls section (Fig. 6).

Description

This light buff coloured lime mudstone facies contains very rare *Amphipora* and thin shelled gastropods (Plate 3E). Planer laminations, 2 to 10 mm thick, are the most distinctive feature of this facies. Irregular patches of calcite spar cement (1 to 2 mm across), which resemble fenestral fabric, are common. The upper boundaries of these laminations are highlighted by dark brown surfaces up to 0.5 mm thick. Some of these laminations have a crinkled pattern which is suggestive of algal laminations

The variable orientation of the fossils indicates that the fossils underwent some transportation. *Amphipora* occur as abraded fragments and the gastropods occur as whole, but abraded shells.

Comparison

Laminated (fenestral) limestones occur in intertidal to supratidal successions at many Devonian localities. Such laminates in the Swan Hills reef were considered supratidal deposits based on the lack of normal benthic fauna, well-preserved laminations, and irregular void spaces filled with calcite cement (Murray, 1966). Similar laminated deposits at Carson Creek North were considered to be supratidal deposits (Leavitt, 1968). Machel (1990) also showed that laminated mudstones formed in the supratidal setting throughout the Devonian of Western Canada and Europe.

6. Oncolite Floatstone-Rudstone Facies

Occurrence

The oncolite floatstone to rudstone facies was only found at one glacially polished surface at kilometre 106.5 of the Mackenzie Highway. It is included here to complete the descriptions of all facies that occur in the Alexandra Formation. This outcrop, however, offers no vertical relief and therefore is not included on the facies sections.

Description

This light brown floatstone-rudstone consists of spherical to elliptical oncolites (8 mm to 3 cm in diameter) in a buff coloured skeletal wackestone matrix (Plate 3F). The irregular cortical layers are highlighted by differential weathering on the surface of the outcrop. Fragments of broken and severally abraded cylindrical stromatoporoids, gastropods, and other unidentifiable grains form the nuclei of these oncolites.

The packstone to grainstone matrix is composed of fragments of brachiopods, corals and crinoids up to 2 mm in size. Locally, the mud is partially dolomitized with subhedral to euhedral, zoned dolomite rhombs. High amplitude stylolites (2 to 7 cm amplitude) occur locally.

Comparison

Most Devonian oncolites appear to have formed in agitated shallow water environments. For example, oncolites (5 mm to 5 cm) occur in turbulent backreef environments of the Upper Leduc formation in the Redwater reef (Klovan, 1964). Murray (1966) and Leavitt (1968) found oncolites in similar environments in the Judy Creek and Carson Creek North reefs. Those oncolites found in muddy matrices showed evidence of transport to a quieter water environment. Sand and gravel sized oncolites were probably formed in shallow, agitated waters in the Alexandra Formation (Jamieson, 1967). The continuity of the coated layers suggested that bottom currents were strong enough to roll up to cobble sized sediment (Jamieson, 1967).

7. Crinoid, Brachiopod, Nodular Floatstone Facies

Occurrence

This facies occurs in the cores from HW-79-9, HW-79-10, HW-79-10, HW-79-13, and HW-81-28 wells (Fig. 6).

Description

This medium grey to greenish grey, argillaceous calcareous, wackestone to floatstone has a distinct nodular texture (Plate 4A). Brachiopods and crinoids dominate the fossil assemblage. Gastropods occur in lesser numbers. Rare shell hash packstone layers up to 15 cm thick are intercalated with the dominant lithology (Plate 4B).

All the fossil material has undergone transportation. Brachiopods occur as whole and disarticulated shell fragments. In the intercalated shell hash layers most of the brachiopods are aligned concave up with some showing imbrication. The crinoids occur as single ossicles and rarely as stalk fragments. Gastropods occur as whole, unabraded shells except in the shell hash layers where the shells are broken and abraded. The matrix is argillaceous. Horsetail stylolites (1 to 2 cm amplitude) and green clay partings are common. A well-developed nodular texture is characteristic of this facies due to the argillaceous nature of the rock. Pyrite cubes (2 to 5 mm) and silt sized, quartz grains occur locally in minor amounts.

Comparison

Nodular limestones with brachiopod and crinoid fossil assemblages are common in the lower foreslope to basinal deposits in the Devonian of Western Canada. For example, nodular to banded limestones containing crinoids and brachiopods occur in the Judy Creek and Kee Scarp reefs (Wendte and Stoakes, 1982; Muir *et al.*, 1984) where deposition probably occurred in the deep, low energy dysaerobic to aerobic environments of the lowermost foreslope. Similar deposits are known from Devonian ramp settings (Cook, 1972; Cutler, 1983; Theriault, 1988). The nodular texture resulted from a combination of burrowing and selective early cementation which was then highlighted by compaction.

PLATE 4

(A) Crinoid - brachiopod nodular floatstone facies. Polished core (19.7 m, well HW-81-28) showing nodular texture developed from compaction of carbonate – rich layers.

(B) Crinoid - brachiopod nodular floatstone facies. Polished core (36.4 m, well HW-79-9) showing bedded shell hash layers with current (?) orientation of the brachiopod shells.

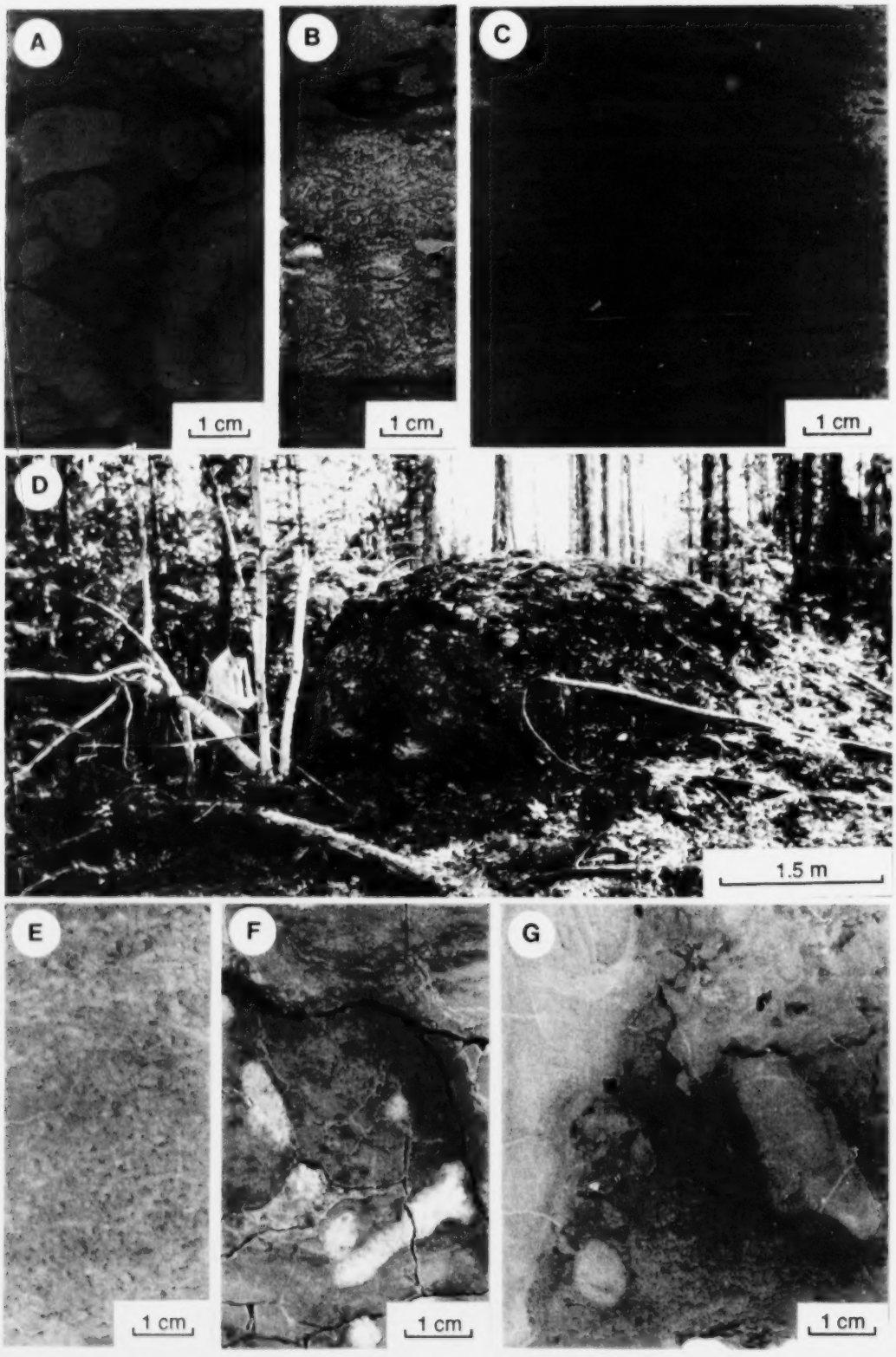
(C) Dolomitic/calcareous siltstone facies. Polished slab showing vague parallel laminations typical of this facies. 0.9 m above section base at Alexander Falls

(D) Mud Mounds. Outcrop photograph showing the mound-shaped structures formed *Amphipora* – tabular stromatoporoid floatstone facies.

(E) Mud Mounds. Polished slab of the *Amphipora* packstone that occurs locally in this facies.

(F) Mud Mounds. Polished slab showing *Thamnopora* floatstone with a skeletal wackestone matrix.

(G) Mud Mounds. Polished slab showing tabular and cylindrical stromatoporoids in a skeletal wackestone matrix.


A
1 cm
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1.5 m
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G
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Argillaceous, nodular limestones with brachiopods occur in the off - reef environments in the Carson Creek North reef complex. There, compaction of thin more carbonate rich beds, forming boudinage structures, created the nodular texture.

8. Calcareous-Dolomitic Siltstone Facies

Occurrence

Calcareous-dolomitic siltstone occurs in outcrop at the Dry Creek, Twin Falls Creek, and Alexandra Falls and in cores from HW-79-9, HW-79-10, HW-79-11, HW-79-13, and HW-81-28 (Fig. 6).

Description

This brownish grey siltstone consists of angular to subangular, silt- to fine sand sized quartz grains with calcite and/or dolomite cement. Alternating dark quartz-rich and light carbonate-rich laminations occur in thin planar to low angle cross beds (Plate 4C). Vertical and horizontal burrows are common.

This facies is compositionally diverse. Quartz content ranges from 10 to 80%, and the amount varies from lamina to lamina. The most common composition is siltstone with 40 to 50% quartz grains with both calcite and dolomite cement. The carbonate cement occurs as anhedral crystals filling the inter-particle porosity. Planar to low angle cross laminated structures occur throughout.

Bedded shell hash layers are locally intercalated with the calcareous/dolomitic siltstone facies. Disarticulated brachiopods are the most common fossil with crinoid ossicles and whole gastropods occurring in lesser numbers. All fossils have abraded outer surfaces. Locally, the brachiopod shell fragments show a distinct alignment, possibly due to the currents that transported the material.

Comparison

This facies, which forms the top of member E of the Escarpment Formation, probably originated on a prograding shallow ramp in a high energy, shallow subtidal

environment (Hadley, 1987; Hadley and Jones, 1990). Current bedded siltstones and fine sandstones and local ripple marked surfaces support this interpretation (Hadley, 1987).

9. *Amphipora*, Tabular Stromatoporoid Floatstone Facies

Occurrence

This facies occurs only in the Mud Mounds section (Fig. 6, Plate 4D).

Description

A light tan floatstone with variable amounts of *Amphipora* (up to 3 mm diameter - Plate 4E), *Thamnopora* (branch fragments up to 2 cm long - Plate 4F), and tabular stromatoporoids (2 to 7 mm thick, 3 to 15 cm diameter - Plate 4G). Crinoids, brachiopods, small colonial heads (up to 15 cm diameter - Plate 4G) and solitary corals (5 mm to 2 cm diameter) are rare.

With the exception of rare tabular stromatoporoids, all the skeletal material has been transported. The *Amphipora* and *Thamnopora* are fragmented and abraded, some showing the effects of post depositional compaction. The small colonial coral heads are overturned and abraded whereas the solitary corals are abraded and occur in variable orientations. The crinoids and brachiopods occur as disarticulated ossicles and shells.

The matrix is a crinoid - brachiopod wackestone. All skeletal material has been transported, fragmented, and abraded. Part of the mud has been replaced by zoned euhedral to subhedral dolomite rhombs. Calcite spar cement fills the inter-particle porosity of the colonial corals and some of the *Amphipora*. The remainder of the porosity is filled with mud. High amplitude (2 to 7 cm amplitudes) stylolites are common.

Comparison

Mud supported skeletal mounds and mound shaped structures are known from other Devonian successions (James and Bourque, 1992). These environments have been compared to the backreef seagrass beds of modern lagoons (Jamieson, 1967). The *Amphipora* would have baffled the mud much as *Thalassia* traps mud into low relief mounds in the Caribbean (Jones and Desrochers, 1992). The mud is either produced *in*

situ as a result of the activity of associated organisms inhabiting the mound or is transported from other mud producing areas of the reef (James and Bourque, 1992). The known occurrence of *Amphipora* in backreef settings from other Devonian successions (Murray, 1966; Leavitt, 1968; Wendte and Stoakes, 1982; Machel, 1990) tends to support a backreef setting.

Another possible environment for the formation of mud-supported mounds is in the forereef environment. Mud mounds are known from foreslope settings where energy conditions are low enough to allow the mud trapped by the skeletal organisms to accumulate (James and Bourque, 1992). The reefs of the Nisku Formation in central Alberta represent deeper water mud supported reefs that have been interpreted as mounds by some workers (Krause, 1984).

10. Green Shale Facies

Occurrence

This facies occurs in HW-79-9, HW-79-10, HW-79-11, HW-79-13, and HW-81-28 (Fig. 6).

Description

This is an olive green calcareous shale with a sparse brachiopod fauna. The shale is fissile to massive with the massive zones having a greater carbonate content. Brachiopods occur as complete, unabraded shells. Some shells have been crushed by later compaction. The variable orientation of the shells suggests that most of the brachiopods have undergone some degree of transportation.

Comparison

Green shales are generally regarded as basinal deposits. Such shales are common in Devonian basins of Western Canada. Green fissile and bioturbated shales containing brachiopods and crinoids form the Ireton Formation of south central Alberta (Stoakes, 1980). The fissile shales formed in dysaerobic environments where sediment ingesting organisms were unable to rework the sediment, preserving the primary laminations.

Bioturbated shales, however, formed in oxygen rich environments where extensive bioturbation could occur thus destroying the original texture.

GEOGRAPHICAL AND STRATIGRAPHIC DISTRIBUTION OF FACIES IN THE ALEXANDRA FORMATION

There are systematic variations in the geographic and stratigraphic distribution of facies in the Alexandra Formation of the Hay River area (Fig. 8). Facies near Alexandra Falls are significantly different from those exposed along the escarpment. These areas, which contain relatively uniform facies successions are separated by an area where the facies interfinger (Fig. 8).

In the Alexandra Falls to Twin Falls Creek area the stromatoporoid, coral floatstone to framestone facies dominates the lower part of the formation. *Amphipora* floatstones-rudstones and laminated mudstones form the upper part of the succession (Fig. 8).

Along the escarpment (McNally Creek, and core from wells HW-79-10, HW-79-11, HW-79-13, and HW-81-28 - Fig. 8) the basal part of the formation is formed of the crinoid, brachiopod nodular floatstone (Fig. 8). The overlying stromatoporoid, coral floatstone to framestone facies is dominated by thick, well-developed tabular stromatoporoid framestones. Locally, (e.g., HW-79-10, HW-79-11, and HW-79-13), cylindrical stromatoporoid floatstones occur in the upper part of the formation. The *Amphipora* floatstones-rudstones and laminated mudstones that dominate the succession in the Alexandra Falls - Twin Falls Creek area do not occur along the escarpment (Fig. 8).

The Alexandra Falls - Twin Falls Creek and Escarpment areas are separated by a transitional area (Quarry 2, well HW-79-9, Dry Creek - Fig. 8) in which facies of both areas interdigitate (Fig. 8). The basal part of the succession in well HW-79-9 is a crinoid, brachiopod, nodular floatstone whereas stromatoporoid, coral floatstone-framestone forms the basal part of the formation in Quarry 2 and Dry Creek (Fig. 8). Cylindrical stromatoporoid floatstones and *Amphipora* floatstones-rudstones

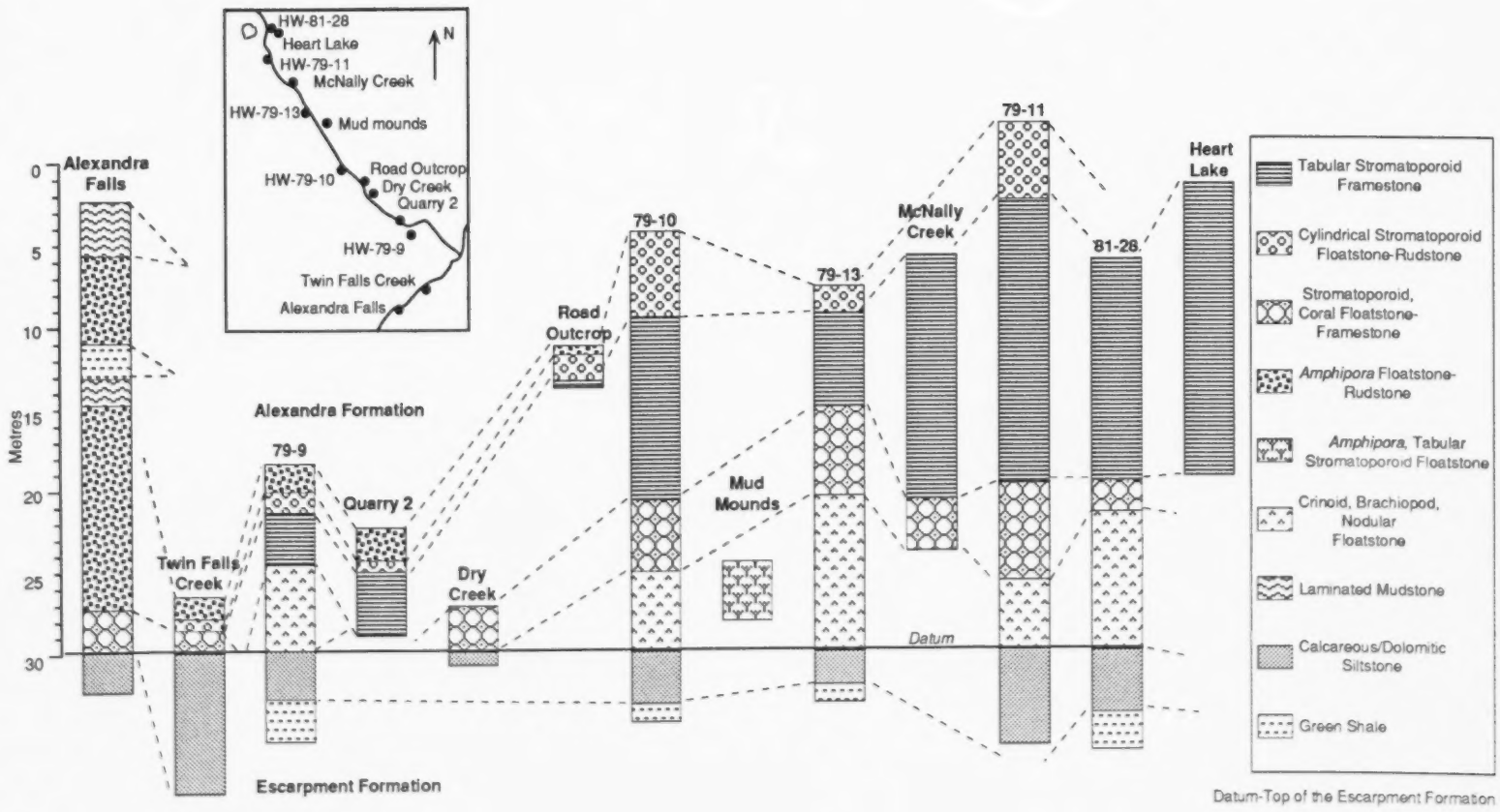

Figure 8. Facies distribution and stratigraphic correlations of the Alexandra Formation Facies. For lithological logs, see Appendix B

occur in upper of the succession at Quarry 2 and well HW-79-9 (Fig. 8). The tabular stromatoporoid framestone occurs in HW-79-9 and Quarry 2 (Fig. 8). Laminated mudstones do not occur in the transition zone.

The most significant lateral facies changes occur in a southwest to northeast direction from Alexandra Falls to the Escarpment (Fig. 8). In contrast the facies patterns are relatively consistent along the escarpment from HW-79-10, HW-79-11, HW-79-13, HW-81-28, Heart Lake, and McNally Creek (Fig. 8). The *Amphipora*, tabular stromatoporoid floatstones of the 'Mud Mounds', which are distinctly different from other facies in the area, probably developed in a different depositional regime.

CHAPTER 3

DISCUSSION

During the Late Devonian, the Hay River - Fort Simpson Formation area lay approximately 8° north of the equator if the paleogeographic reconstructions of Scotese and Morrow (1990) are accepted (Fig. 9). As such, this region would have been covered by warm tropical seas. Analogy with modern tropical oceans such as the Caribbean Sea suggests that this would have favored extensive carbonate production and an abundant diverse biota.

Consideration of the paleogeographic setting of the Northern Alberta - Southern Northwest Territories area suggests that deposition occurred on a stable platform that is herein termed the Hay River Platform (Moore, 1988). Tectonic influence was minimal during deposition of the Alexandra Formation with no evidence that the large basement faults in the underlying Precambrian were active (Hadley, 1987; Hadley and Jones, 1990; this study). The Tathlina High, which influenced deposition of the underlying Middle Devonian successions, did not affect deposition of Late Devonian sediments (Belyea and McLaren, 1962; Belyea and Norris, 1962; Belyea, 1971; Hadley, 1987).

Facies successions in the Alexandra Formation form northwest - southeast trending belts that parallel the escarpment (Fig. 10). The constant, uninterrupted lateral nature of the facies shows that the broad Hay River Platform (Belyea and Norris, 1962; Moore, 1988), defined by the Slave Point Formation depositional edge, could not have undergone significant tectonic disturbance. This supports the theory that the escarpment is a depositional remnant of the platform to basin transition rather than a tectonically controlled feature as suggested by Jamieson (1967).

Locally, post depositional faulting produced minor normal faults with 3 to 5 m displacement (e.g., McNally Creek).

Figure 9. Position of the North American continent, Late Devonian
(After Scotese and Morrow , 1990.)

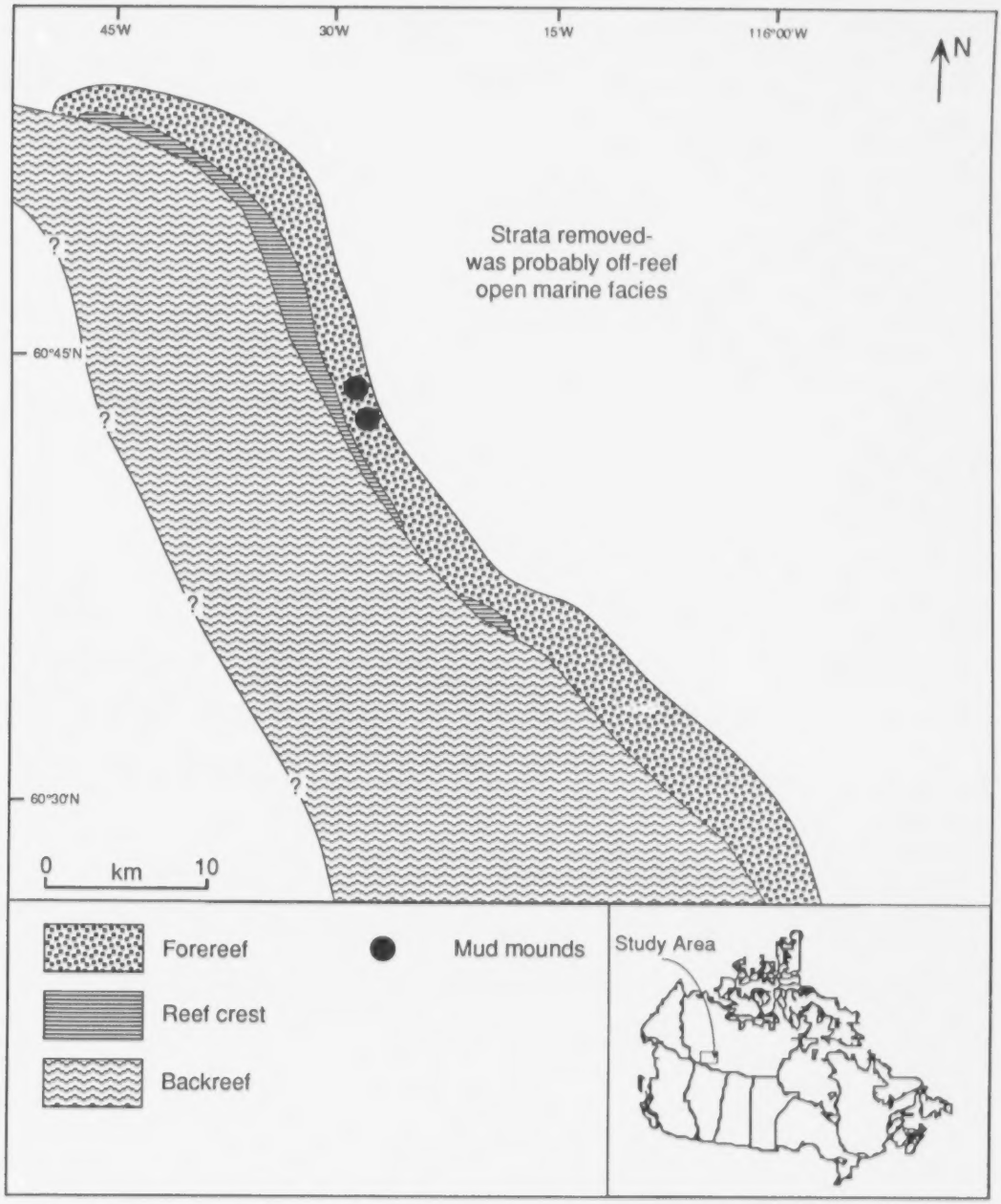

Figure 10. Linear distribution of facies in the upper Alexandra Formation.

DEPOSITIONAL MODEL FOR THE ALEXANDRA FORMATION

The depositional model for the Alexandra Formation is based on the spatial integration of the facies and their characteristic features. The proposed model involves two stages that are at present oriented in a southwest-northeast direction. The first stage (Fig. 11), represented by the lower part of the Alexandra Formation, involved a shallow ramp (cf. Jones and Desrochers, 1992) which prograded over the more basinal lithologies of the Escarpment Formation whereas the second stage, represented by the upper part of the Alexandra Formation, involved a rimmed shelf (Fig. 12). The rim, in this case an organic reef, separated and partially restricted the backreef lagoon from the open marine forereef. The backreef lagoon sediments passed laterally into supratidal deposits. Paleoenvironmental conditions to the northeast cannot be determined because erosion has removed equivilent strata.

Stage I: Ramp

The ramp was characterized by low to moderate energy conditions and good circulation. The facies assemblage is similar to other Devonian ramps (cf. Cook, 1972; Cutler, 1983; Theriault, 1988). Initially, well circulated, moderate energy conditions existed nearshore where the stromatoporoid, coral floatstone-framestone was deposited. At the same time, lower energy, deeper water conditions over the outer part of the ramp led to deposition of the crinoid, brachiopod, nodular floatstone (these nodular floatstones are not exposed on the escarpment but occur below the level of the escarpment base in the cores). Although deposited below normal wave base, this area was periodically affected by storm that produced localized shell hash beds. With time, regressive conditions (with possible additional accommodation from the buildup of the "proto reefs" on the platform) led to the progradation of the shallower water stromatoporoid, coral floatstone to framestone facies over the entire ramp.

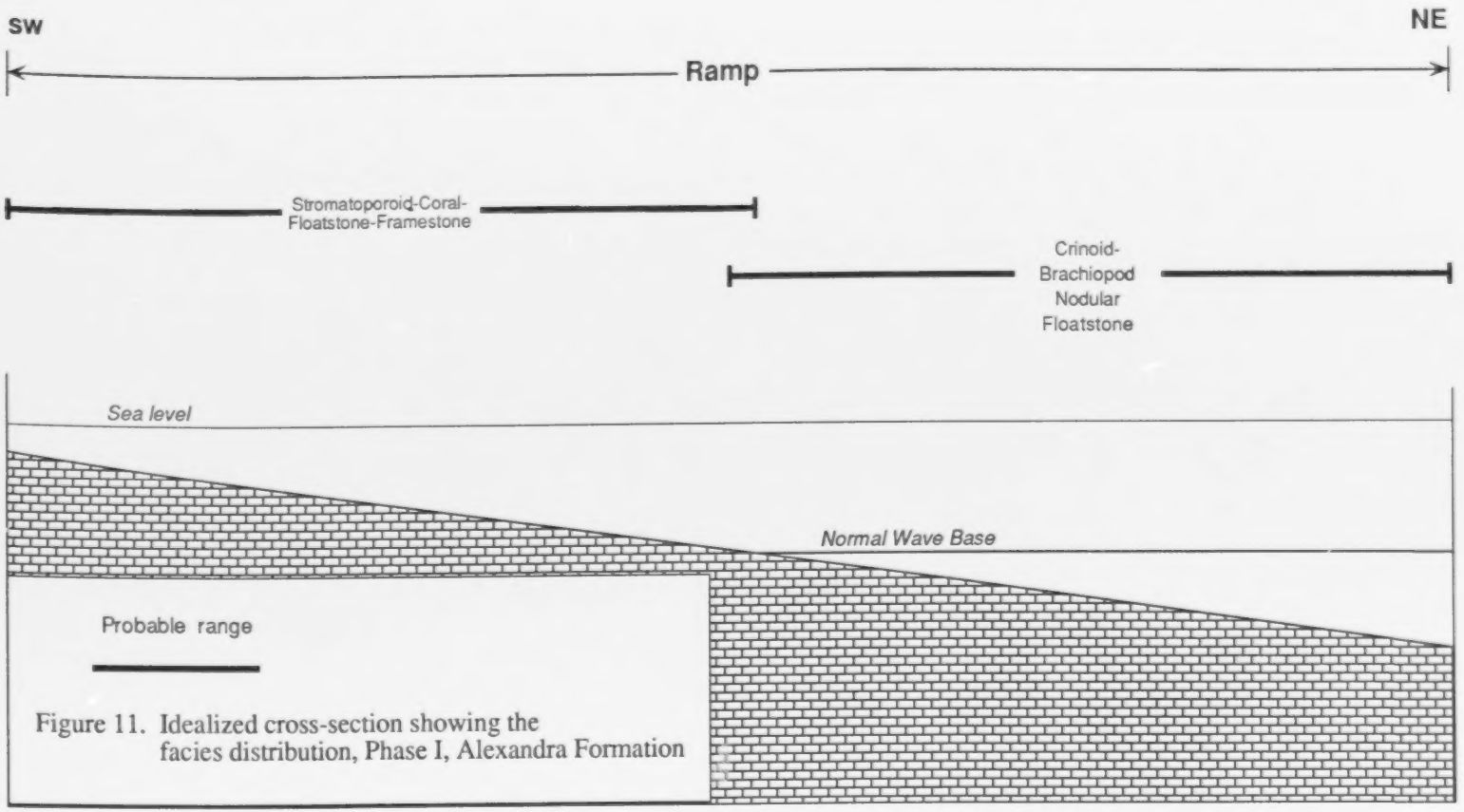

Figure 11. Idealized cross-section showing the facies distribution, Phase I, Alexandra Formation

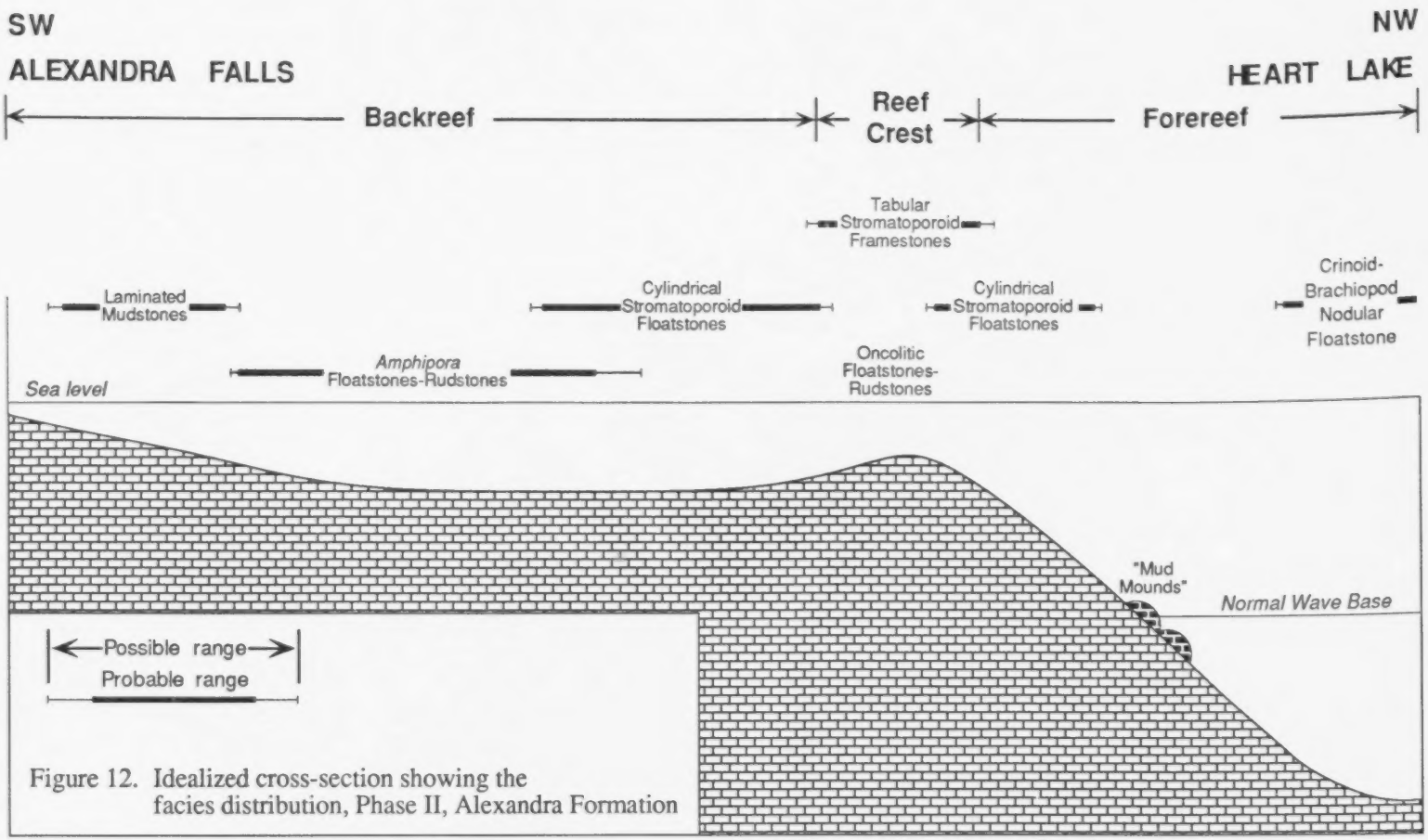

Figure 12. Idealized cross-section showing the facies distribution, Phase II, Alexandra Formation

Stage II: Rimmed Shelf

The second stage, a rimmed shelf, began with reef initiation on the outer part of the ramp. The development of these reefs produced a complex environmental architecture, the focus being the reef that separated open marine conditions from the more restricted backreef. Dissipation of wave energy on the reef crest meant that circulation in the backreef was limited.

Forereef

The forereef environment was divided by normal wave base into the upper and lower regimes. The relatively steep slopes in the forereef produced narrow forereef facies bands. Energy conditions were high in the upper foreslope but low in the lower foreslope. Crinoid, brachiopod, nodular floatstones continued to be deposited in the lower foreslope where quiet conditions were maintained.

The cylindrical stromatoporoid floatstone-rudstone facies formed under high energy conditions in the upper foreslope. Energy conditions were such that only robust branching organisms could survive. Interstitial material was removed, leaving open pore space between the frame-building organisms. Precipitation of calcite cement in these pores was promoted by the high energy conditions that existed at the reef crest (cf. James and Choquette, 1990). Similar high energy forereef deposits, dominated by branching organisms, are known from modern (e.g., James, 1983) and ancient (e.g., Murray, 1966; Leavitt, 1968; Krebs and Mountjoy, 1972; Wendte and Stoakes, 1982; Fischbuch and Havard, 1977; Tooth and Davies, 1987; Davies and Tooth, 1987) reefs.

The mud mounds formed under moderate energy conditions near normal wave base where good circulation allowed some corals and stromatoporoids to survive. Energy levels, however, were low enough to allow mud to accumulate between the organisms. The beds of *Amphipora*, however, probably originated through transportation of *Amphipora* from the back reef environment where it flourished. This occurred where a

break in the reef at the shelf edge allowed material to be transported from the backreef to the forereef.

Reef Crest

The reef crest was a wave resistant structure formed by the growth of tabular stromatoporoids under high energy conditions. The dominance of the encrusting tabular stromatoporoid indicates a stressed environment, probably caused by high energy conditions at the reef crest (Fig. 12). This parallels modern reefs which are commonly characterized by low biotic diversity and robust corals that can withstand the high energy of the waves (James, 1983; James and Bourque, 1992). The high energy conditions also produced the gravel sized skeletal debris that occurs in some parts of the reef.

The oncolitic floatstone-rudstone formed behind the reef crest where waves washing over the reef provided the energy needed to roll them. Most oncolites developed around cylindrical stromatoporoids, derived from adjacent areas, because their shape was ideally suited for rolling.

Backreef

The backreef lagoon was characterized by low to moderate energy conditions, primarily because most of wave energy was dissipated at the reef crest. In general, the energy conditions were progressively reduced in a shoreward direction because of increasing distance from the reef crest. The cylindrical stromatoporoid floatstone facies, *Amphipora* floatstone-rudstone facies, and laminated mudstone facies formed in this lagoon.

The cylindrical stromatoporoid floatstone represents the highest energy backreef deposit in the Alexandra Formation. Formed immediately behind the reef crest, this facies developed under the influence of wash - over wave energy from the reef crest. Relatively good circulation allowed some corals and tabular stromatoporoids to flourish. As with modern and other ancient reefs, robust branching stromatoporoids grew behind the reef

crest where energy levels were moderately high due to wash-over (James, 1983; James and Bourque, 1992). Unlike the upper forereef, however, energy levels were not sufficient to remove the micrite. *Amphipora*, transported from the lagoon interior, occurs locally. This facies grades laterally and vertically into the *Amphipora* floatstone and rudstone facies.

The *Amphipora* floatstone-rudstone, with a high micrite content, originated in the interior part of the lagoon. The light matrix colour (cf. Wendte and Stoakes, 1982; Muir *et al.*, 1984), rare corals, and *in situ* tabular stromatoporoids suggests that there was still some circulation in this part of the lagoon.

The low biotic diversity and algal laminae of the laminated mudstones suggest that they may have originated in low energy, intertidal to supratidal conditions (cf. Mountjoy, 1975; Shinn, 1983; Machel, 1990). The lack of rip up clasts and disrupted algal laminations show that these deposits did not originate in a high energy supratidal setting. The *Amphipora* and gastropods in this facies are like those in the nearby lagoon.

GENERAL PALEOENVIRONMENTAL SETTINGS

Regional eustatic sea level curves, such as that produced by Johnson *et al.* (1985) indicate an overall sea level rise during the period in which the sediments of the Fort Simpson Formation, Escarpment Formation, and Twin Falls Group were deposited. Deposition of the Alexandra Formation represents a continuation of the regressive sedimentation cycle that began with the deposition of unit 4 of the Fort Simpson Formation and continued throughout the deposition of the Escarpment and Alexandra formations (Hadley, 1987; Hadley and Jones, 1990). The preceding transgressive event (Hadley, 1987; Hadley and Jones, 1991), from the top of the Slave Point Formation to unit 4 of the Fort Simpson Formation agrees with the eustatic sea level curve proposed by Johnson *et al.* (1985). Local influences (probably regional tectonic uplifting) must have occurred during deposition of unit 4 such that eustatic sea level rise was not able to keep pace with the local changes.

The Escarpment Formation consisted of shallow ramp lithologies that prograded over deep ramp lithologies with local influxes of terrigenous sediments. Relatively high energy conditions allowed the deposition of the calcareous siltstones and sandstones of Member E at the top of the Escarpment Formation to be deposited on a prograding shallow ramp environment. Conditions stabilized as the influx of the quartz silt material ceased thereby allowing carbonate sediments of the basal Alexandra Formation to accumulate. As shallow water stromatoporoid, coral floatstones to framestones prograded basinward, local platform highs developed as a result of the branching organisms baffling sediments. The incipient reef development that occurred on those highs led to the development of a rimmed shelf. As a result of the reef, a circulation barrier was created, separating and restricting the interior shelf from the open marine circulation. Distinct forereef, backreef and reef crest environments were developed during this time.

The overlying unnamed formation of the Twin Falls Group denotes the onset of a minor transgression which ultimately drowned the reefs of the Alexandra Formation. Fluctuating water depths gave rise to deeper-water argillaceous carbonates and shallower water coral bioherms. Basal beds exposed at Alexandra Falls consist of nodular, highly bioturbated wackestones to packstones (McLean *et al.*, 1987). Upstream on Hay River, a small bioherm, dominated by colonial rugose corals and *Thamnopora* shows that shallower water conditions persisted in this part of the formation. The bioherm is overlain by a distinctive purple crinoid brachiopod packstone.

CONCLUSIONS

1. This unit, previously referred to as the Alexandra Member of the Twin Falls Formation is herein given formation status in the Twin Falls Group because of its unique lithological character and widespread distribution.
2. Limestones of the basal Alexandra Formation accumulated on a shallow ramp. Crinoid, brachiopod nodular floatstone formed on the deeper parts whereas stromatoporoid, coral floatstone to framestones formed in the shallower water.

3. With subsequent progradation, reef initiation occurred on the outer part of the ramp. With time this produced a rimmed shelf with an intricate set of facies that were controlled by energy levels.
4. Limestones of the upper Alexandra Formation accumulated on a rimmed shelf. High energy tabular stromatoporoids framestones and oncolitic gravels formed the reef crest. Low energy crinoid, brachiopod nodular floatstones occurred in the lower foreslope with moderate to high energy cylindrical stromatoporoid floatstone-rudstones occurring on the upper foreslope. The backreef lagoon was characterized by low energy conditions that favored development of cylindrical stromatoporoid floatstones, *Amphipora* floatstones-rudstones, and supratidal algal mats.

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APPENDIX A

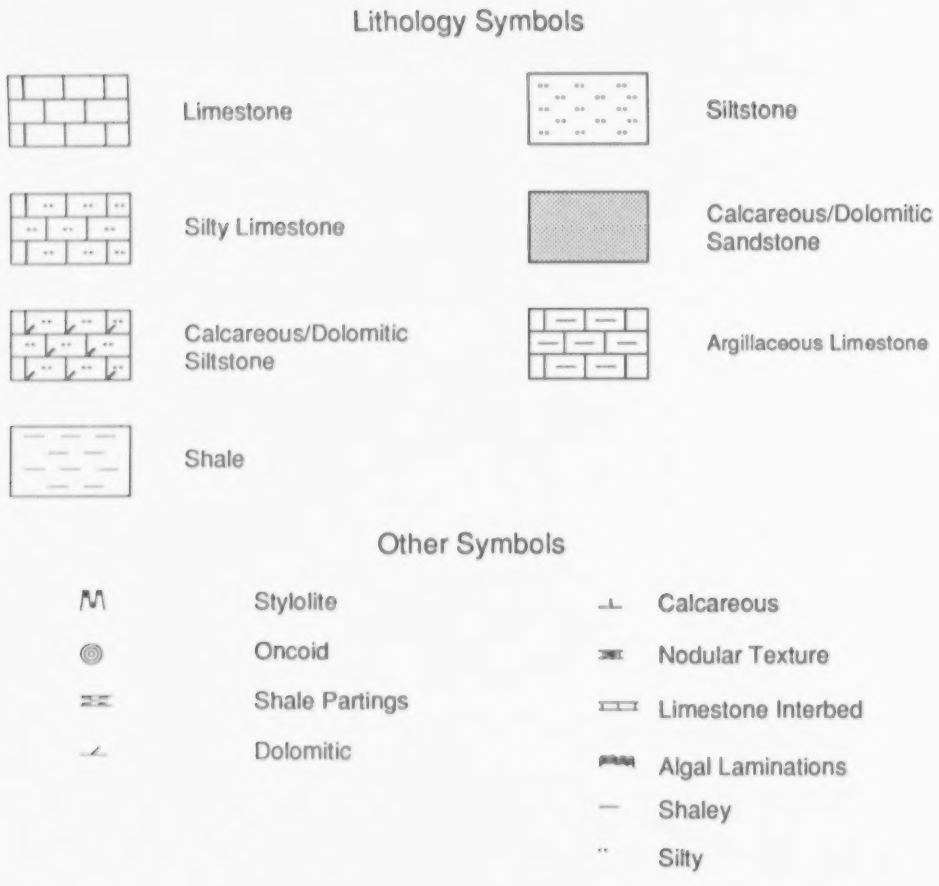

Figure A-1. Legend for the lithological and faunal logs of the Alexandra Formation

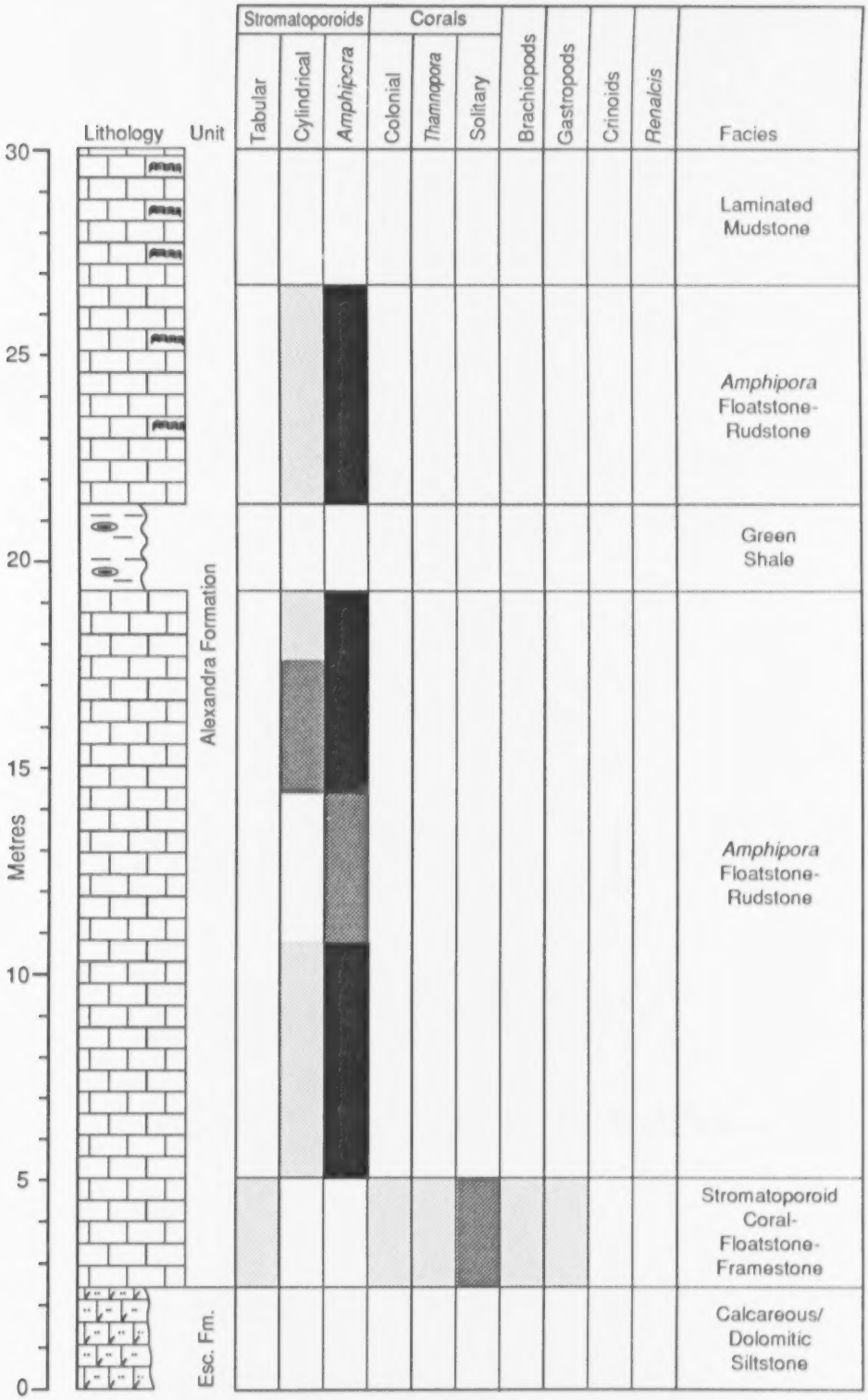

Figure A-2. Lithology and fauna in the Alexandra Formation, Alexandra Falls

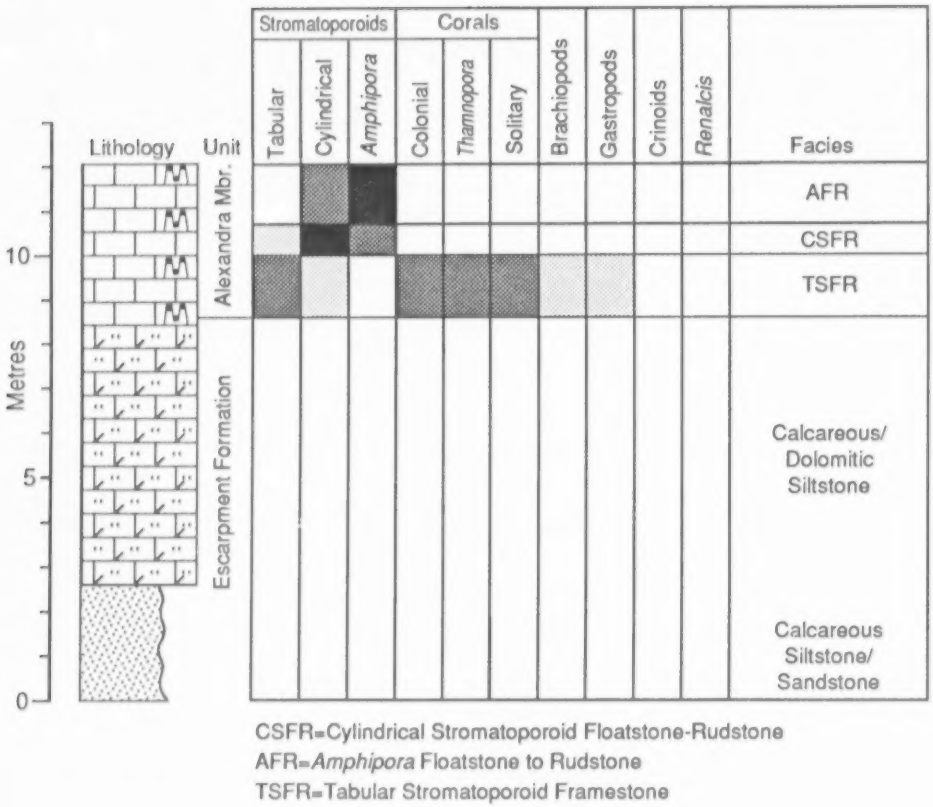

Figure A-3. Lithology and fauna in the Alexandra Formation, Twin Falls Creek

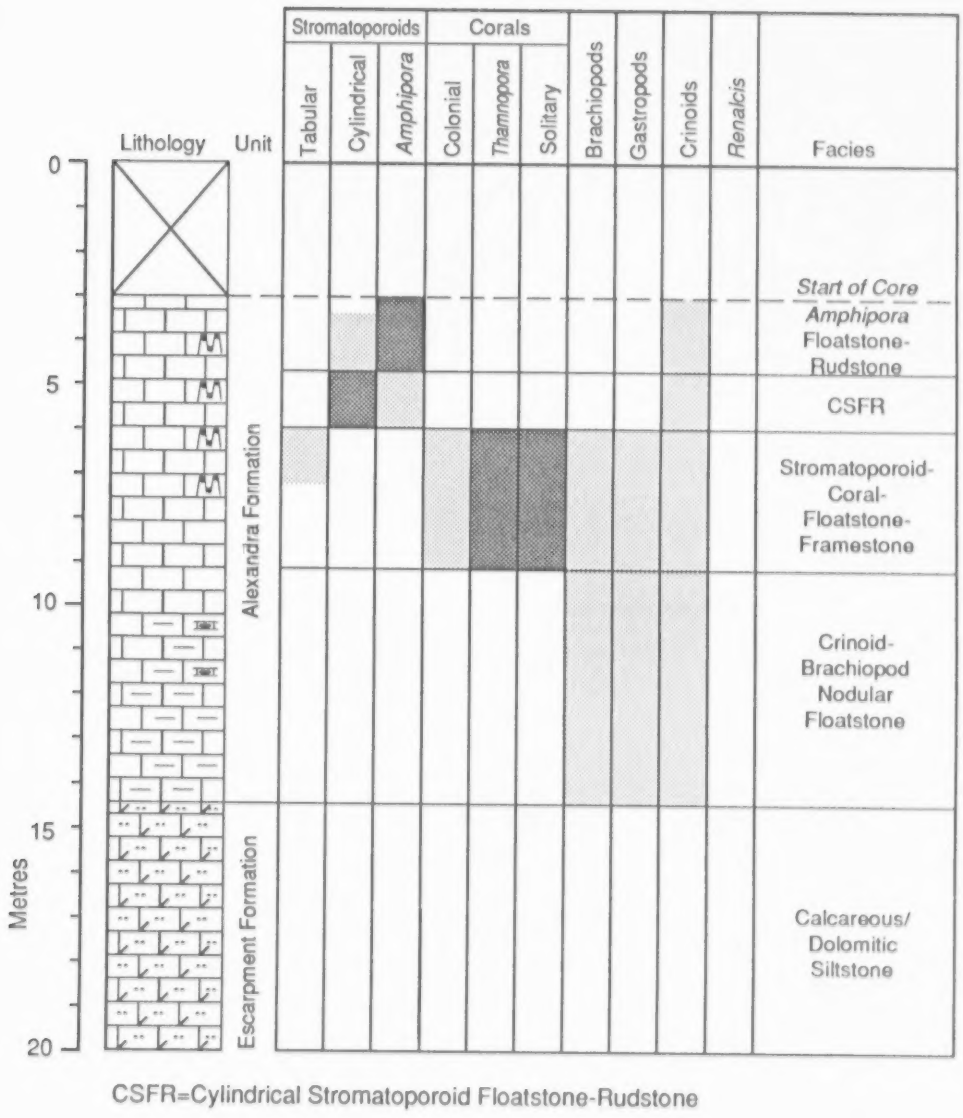

Figure A-4. Lithology and fauna in the Alexandra Formation, Well 79-9

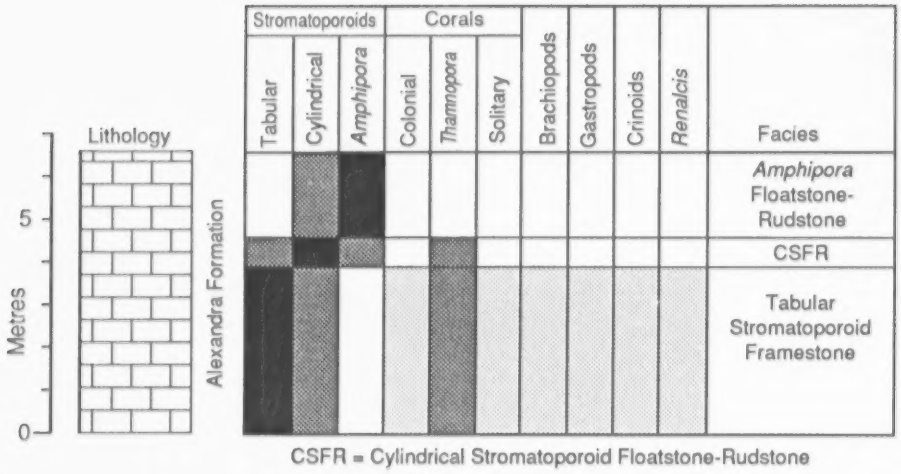

Figure A-5. Lithology and fauna in the Alexandra Formation, Quarry 2

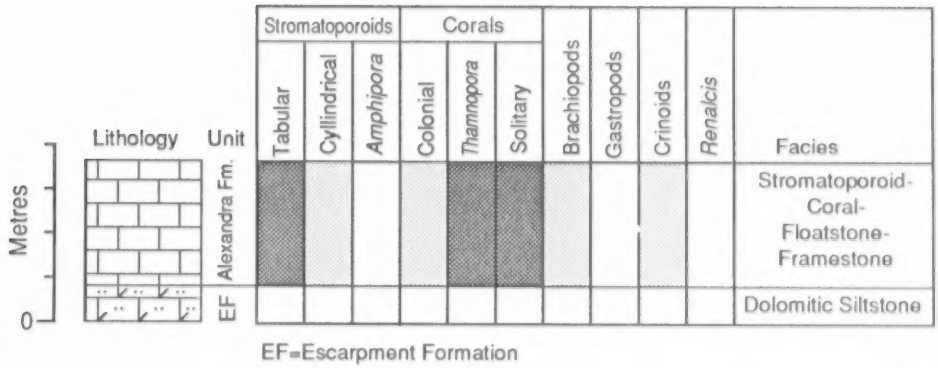

Figure A-6. Lithology and fauna in the Alexandra Formation, Dry Creek

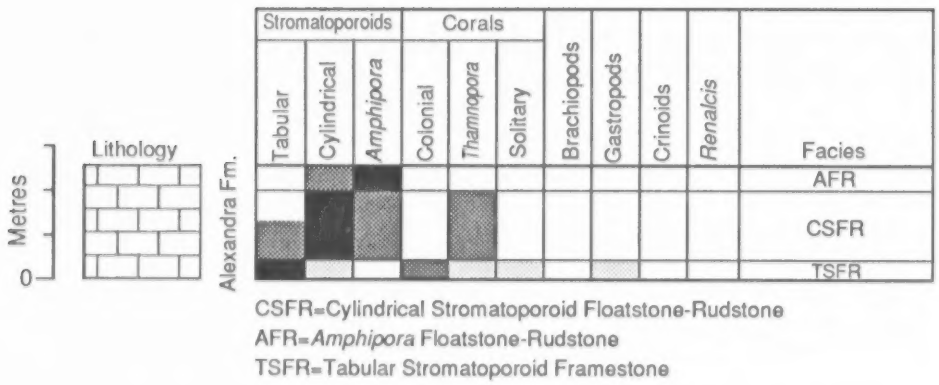

Figure A-7. Lithology and fauna in the Alexandra Formation, Road Outcrop, 60° 38' 07" N, 116° 21' 00" W.

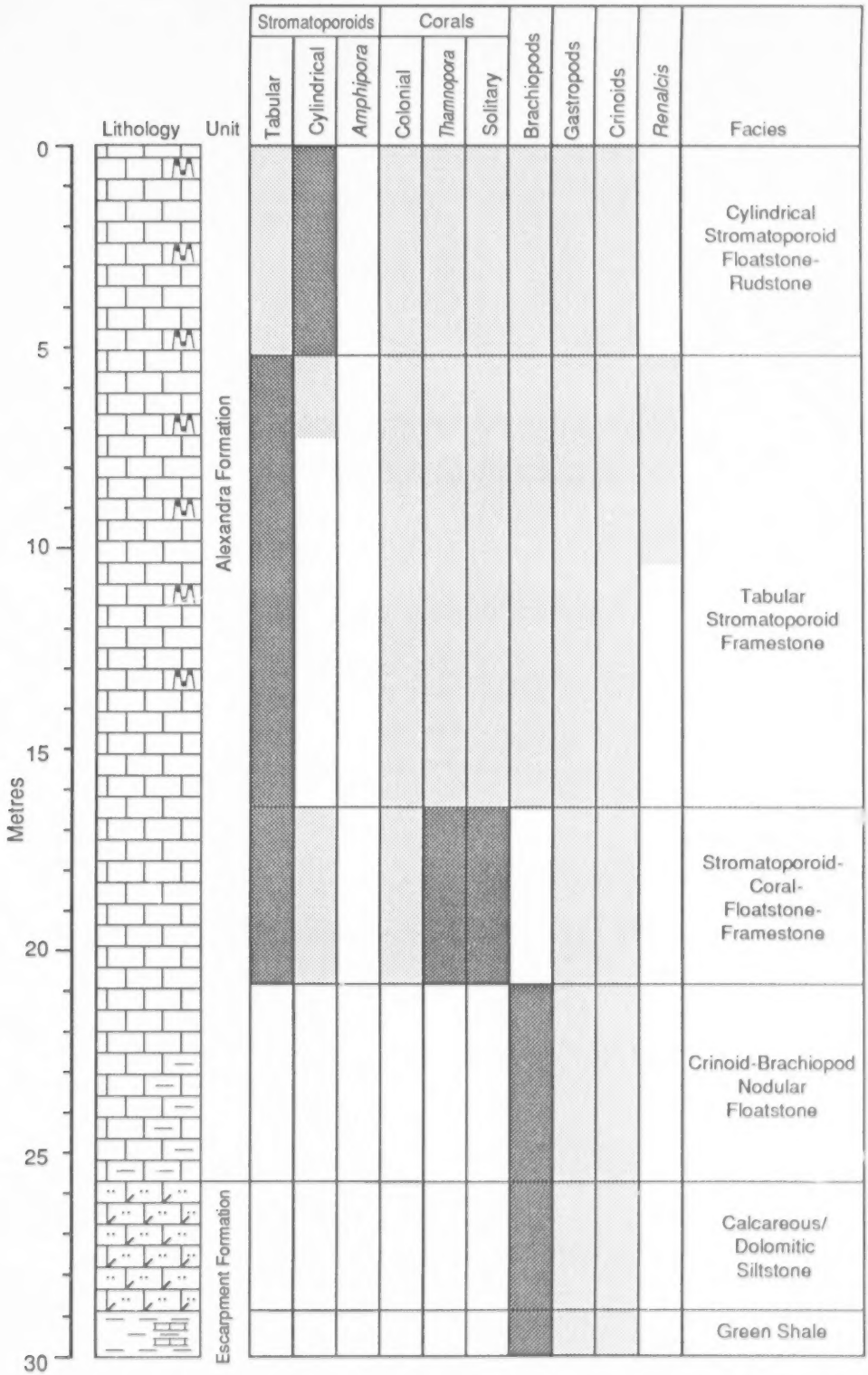

Figure A-8. Lithology and fauna in the Alexandra Formation, Well 79-10

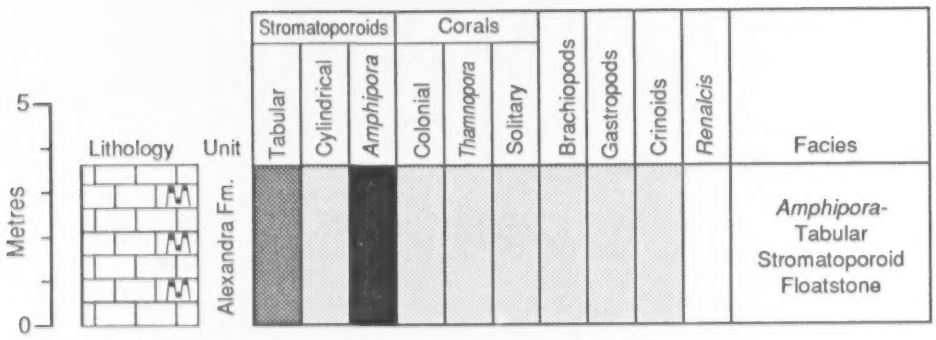

Figure A-9. Lithology and fauna in the Alexandra Formation, Mud Mounds, 60° 41' 48" W, 116° 27' 48" N.

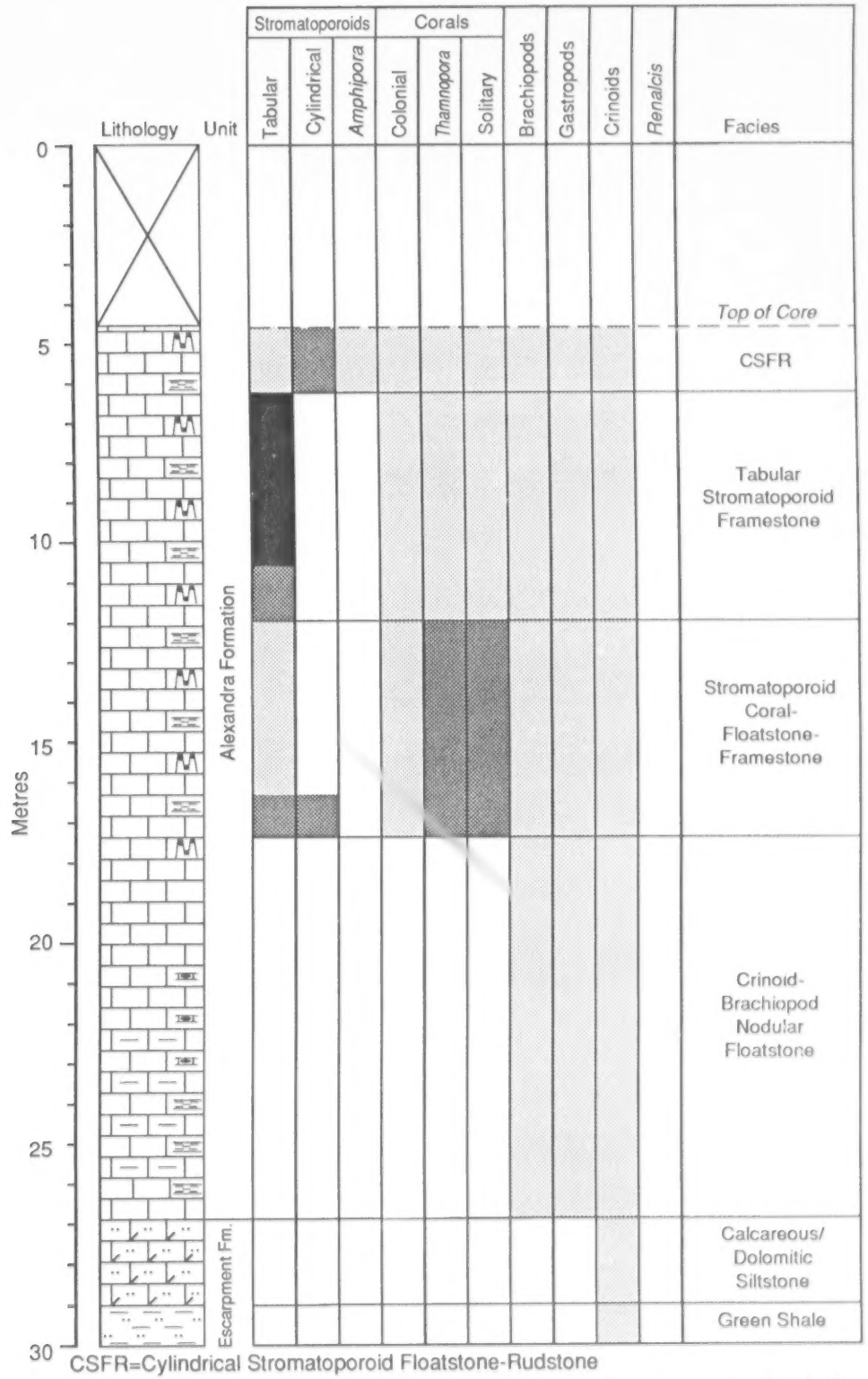

Figure A-10. Lithology and fauna in the Alexandra Formation, Well 79-13

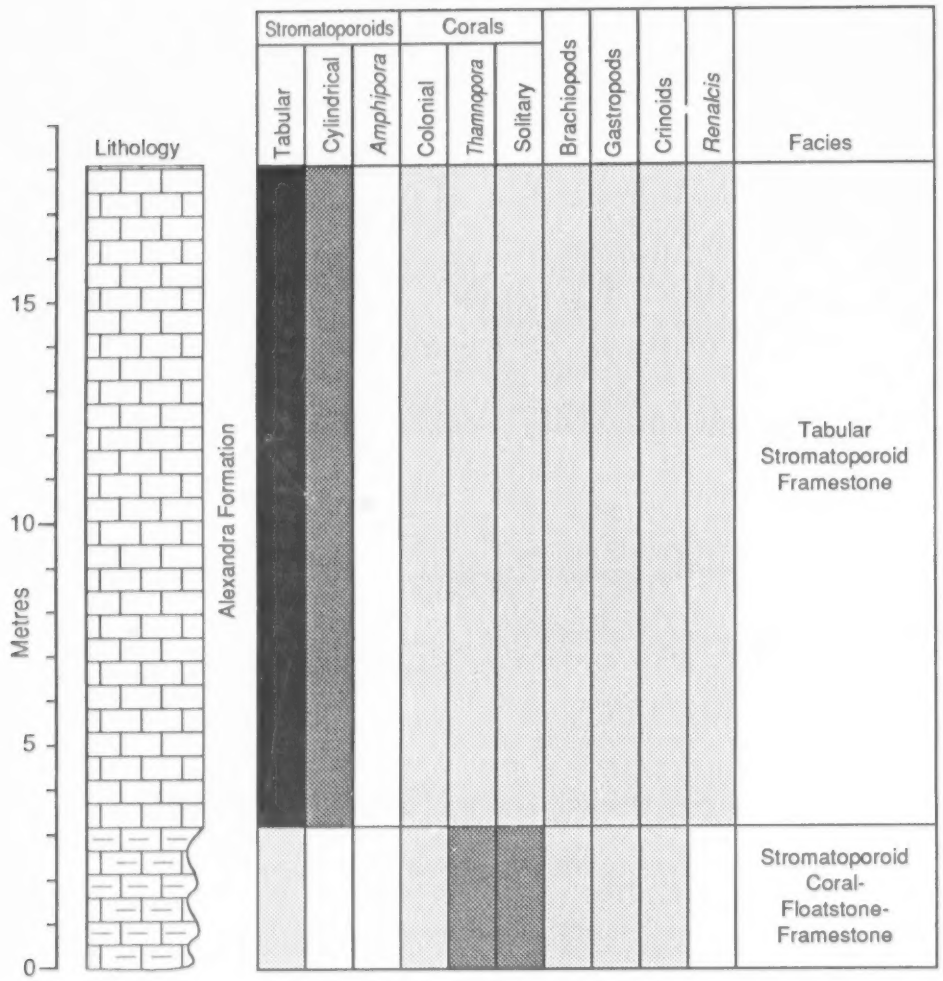

Figure A-11. Lithology and fauna in the Alexandra Formation, McNally Creek

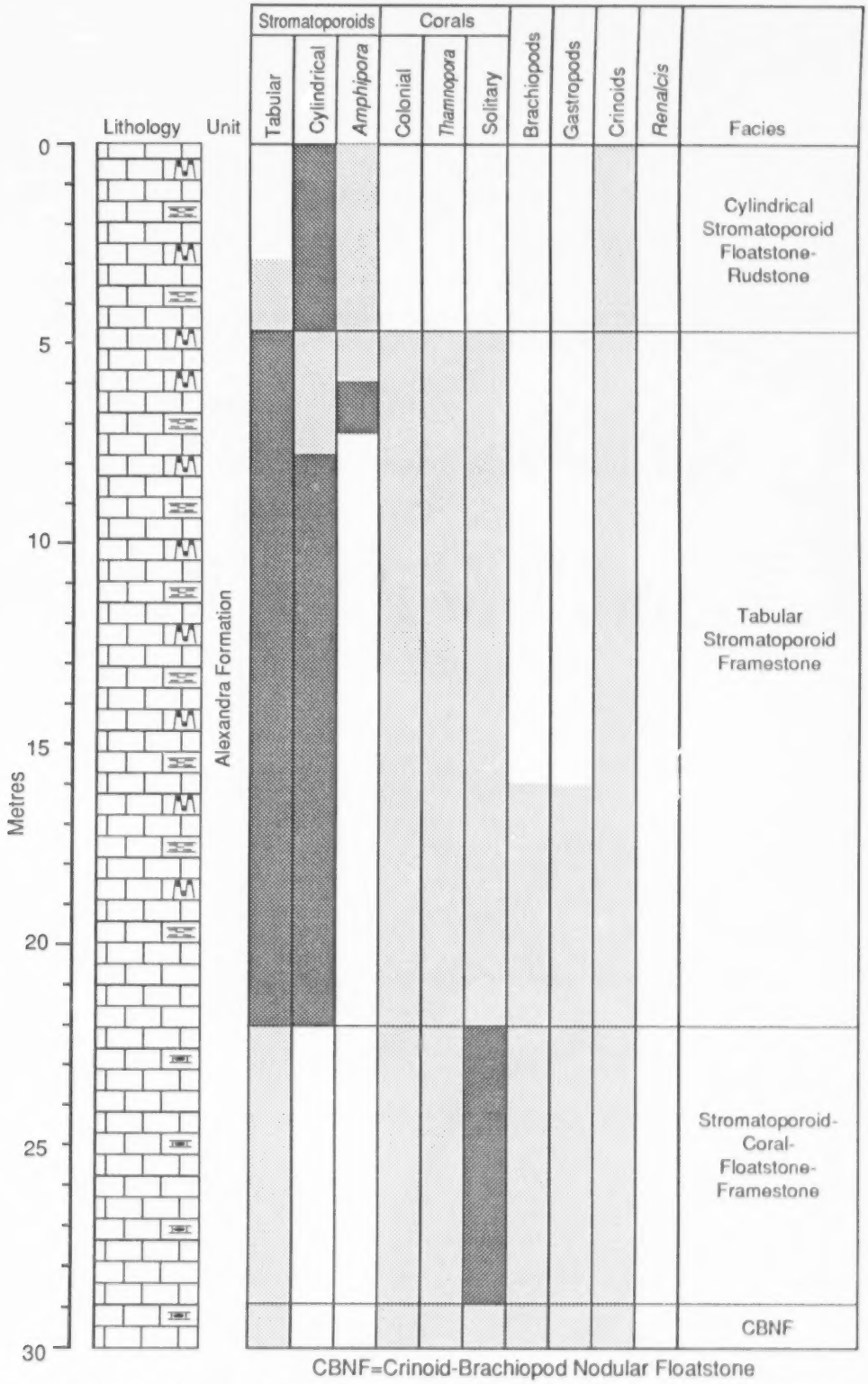

Figure A-12. Lithology and fauna in the Alexandra Formation, Well 79-11

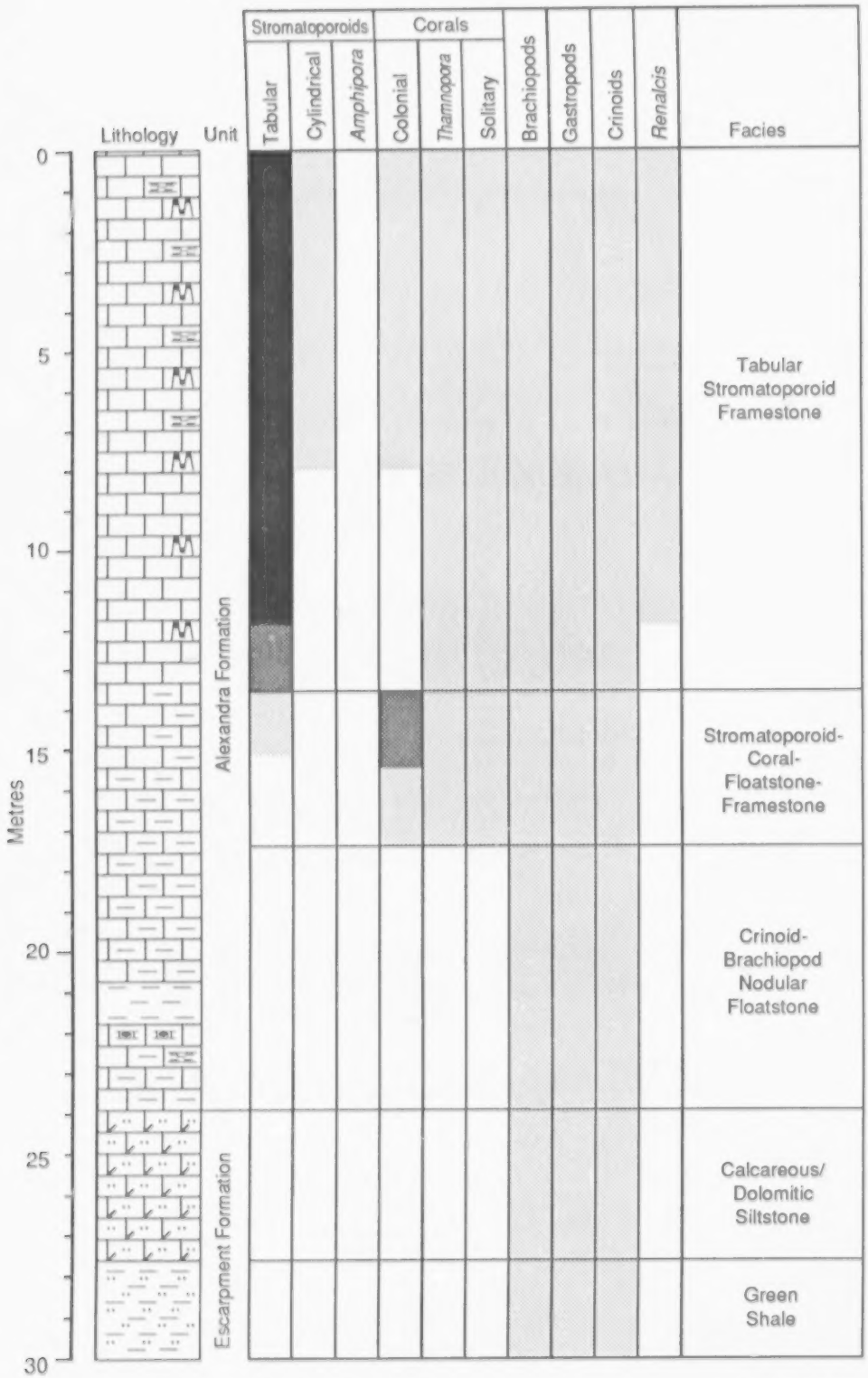

Figure A-13. Lithology and fauna in the Alexandra Formation, Well 81-28.

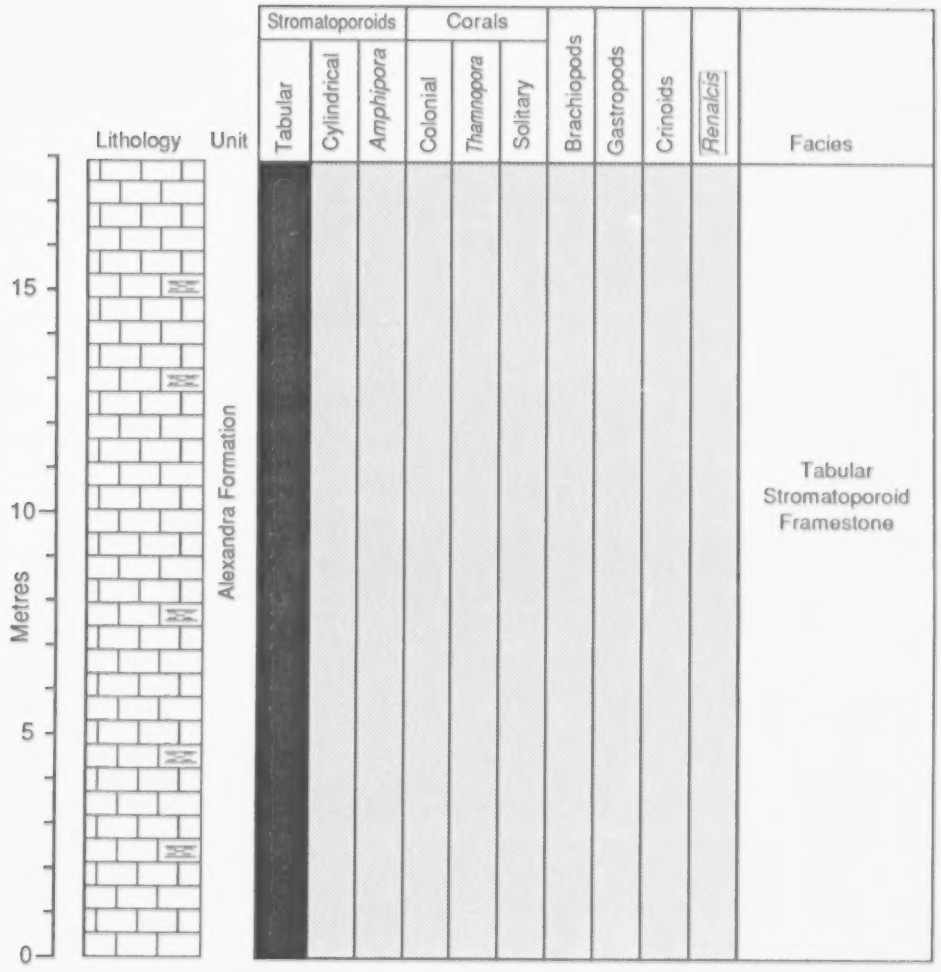

Figure A-14. Lithology and fauna in the Alexandra Formation, Heart Lake

APPENDIX B

WELL AND OUTCROP LOCATIONS EXAMINED IN THE STUDY

WELL	OUTCROP	LATITUTE	LONGITUDE
HW-79-9		60° 35' 30" N	116° 14' 35" W
HW-79-10		60° 40'00" N	116° 24' 30" W
HW-79-11		60° 48' 00" N	116° 36' 25" W
HW-79-13		60° 44' 15"N	116° 24' 36" W
HW-81-28		60° 50' 20" N	116° 35' 55" W
Murphy Canada Alexandra Falls No. 2		60° 15' 31" N	116° 34' 42" W
Union Alexandra Falls Test No. 1		60° 27' 15" N	116° 21' 00" W
	Alexandra Falls	60° 30' 00" N	116° 16' 23" W
	Twin Falls Creek	60° 31' 29" N	116° 12' 30" W
	Quarry 2	60° 36' 30" N	116° 21' 30" W
	Dry Creek	60° 37' 50" N	116° 20' 48" W
	Road Outcrop	60° 38' 07" N	116° 21' 00" W
	Mud Mounds	60° 41' 48" N	116° 27' 48" W
	McNally Creek	60° 46' 37" N	116° 34' 35" W
	Heart Lake	60° 50' 20" N	116° 35' 55" W

APPENDIX C

List of Samples Collected

TS-Thin Section Taken

PS-Polished Slab

AP-Acetate Peel

SEM-Scanning Electron Microscope

ISO-Isotope Data

List of Core Samples and Thin Sections Taken From Core

Alexandra Formation Core Stored at the University of Alberta

HW-79-9
HW-97-10
HW-79-11
HW-79-13

Thin Sections Taken From Core (all depths in metres)

HW-79-9	4.7	5.4	6.6	7.2	7.4	9.0	18.4			
HW-79-10	0.1	2.2	7.3	14.2	14.7	17.5	18.5	20.5	23.3	25.1
HW-79-11	2.3	4.2	4.8	8.8	14.9	22.6	22.9	26.5	28.0	36.4
HW-79-13	4.9	5.5	6.3	10.3	13.0	14.3	17.0	17.9	21.7	
HW-81-28	0.3	3.6	5.3	5.4	8.2	9.3	10.8	12.2	13.5	14.9
HW-81-28	15.9	17.7	21.9	25.2						

NO.	OLD NO.	FORMATION	LOCATION	DESCRIPTION	TS	PS	AP	SEM	ISO	THESIS
HR-801	HR-801	Alexandra	Road Outcrop	Muddy limestone possible fenestral fabric		X				JB
HR-802	HR-802	Alexandra	Road Outcrop	Muddy limestone possible fenestral fabric		X				JB
HR-803	HR-803	Alexandra	Road Outcrop	Coarser grained lime mudstone	X					JB
HR-804	HR-804	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone						JB
HR-805	HR-805	Alexandra	Road Outcrop	Fine grained fenestral(?) fabric						JB
HR-806	HR-806	Alexandra	Road Outcrop	*Amphipora* floatstone						JB
HR-807	HR-807	Alexandra	Road Outcrop	Tabular stromatoporoid floatstone		X				JB
HR-808	HR-808	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-809	HR-809	Alexandra	Road Outcrop	*Amphipora* packstone with black stylolite		X				JB
HR-810	HR-810	Alexandra	Road Outcrop	Cylindrical-tabular stromatoporoid floatstone						JB
HR-811	HR-811	Alexandra	Road Outcrop	Cylindrical-tabular stromatoporoid floatstone		X				JB
HR-812	HR-812	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-813	HR-813	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-814	HR-814	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-815	HR-815	Alexandra	Road Outcrop	Cylindrical, tabular stromatoporoids						JB
HR-816	HR-816	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-817	HR-817	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-818	HR-818	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-819	HR-819	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-820	HR-820	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone		X				JB
HR-821	HR-821	Alexandra	Road Outcrop	*Amphipora* floatstone		X				JB
HR-822	HR-822	Alexandra	Road Outcrop	Tabular stromatoporoid framestone						JB
HR-823	HR-823	Alexandra	Road Outcrop	Tabular stromatoporoid framestone	X					JB
HR-824	HR-824	Alexandra	Road Outcrop	Tabular stromatoporoid framestone		X				JB
HR-825	HR-825	Alexandra	Road Outcrop	Tabular stromatoporoid framestone		X				JB
HR-826	HR-826	Alexandra	Road Outcrop	Tabular stromatoporoid framestone		X				JB
HR-827	HR-827	Alexandra	Road Outcrop	Tabular stromatoporoid floatstone-framestone		X				JB
HR-828	HR-828	Alexandra	Road Outcrop	Tabular stromatoporoid floatstone-framestone						JB
HR-829	HR-829	Alexandra	Road Outcrop	Tabular stromatoporoid floatstone-framestone						JB
HR-830	HR-830	Alexandra	Road Outcrop	Cylindrical stromatoporoid floatstone	X					JB
HR-831	HR-831	Alexandra	Road Outcrop	Tabular stromatoporoid framestone						JB
HR-832	HR-832	Alexandra	Road Outcrop	Colonial coral head		X				JB

HR-833	HR-833	Alexandra	Road Outcrop	Crinoids in a wackestone matrix						JB
NO.	OLD NO.	FORMATION	LOCATION	DESCRIPTION	TS	PS	AP	SEM	ISO	THESIS
HR-834	HR-834	Alexandra	Quarry 2	Leached stromatoporoid-coral at the base of Quarry	X					JB
HR-835	HR-835	Alexandra	Quarry 2	Vuggy dolostone with leached moldic porosity		X				JB
HR-836	HR-836	Alexandra	Quarry 2	Coral-cylindrical-tabular stromatoporoids. Limestone		X				JB
HR-837	HR-837	Alexandra	Quarry 2	Tabular stromatoporoids and solitary coral floatstone	X					JB
HR-838	HR-838	Alexandra	Quarry 2	Tabular stromatoporoid floatstone						JB
HR-839	HR-839	Alexandra	Quarry 2	Cylindrical stromatoporoid floatstone		X				JB
HR-840	HR-840	Alexandra	Quarry 2	Cylindrical stromatoporoid floatstone		X				JB
HR-841	HR-841	Alexandra	Quarry 2	Cylindrical stromatoporoid floatstone						JB
HR-842	HR-842	Alexandra	Quarry 2	*Amphipora* floatstone to rudstone		X				JB
HR-843	HR-843	Alexandra	Quarry 2	*Amphipora* floatstone to rudstone		X				JB
HR-844	HR-844	Escarpment	Quarry 1	Argillaceous mudstone to wackestone						JB
HR-845	HR-845	Escarpment	Quarry 1	Argillaceous mudstone to wackestone						JB
HR-846	HR-846	Escarpment	Quarry 1	Argillaceous mudstone to wackestone						JB
HR-847	HR-847	Escarpment	Quarry 1	Argillaceous mudstone to wackestone						JB
HR-848	HR-848	Escarpment	Quarry 1	Argillaceous mudstone to wackestone						JB
HR-849	HR-849	Escarpment	Quarry 1	Argillaceous mudstone to wackestone						JB
HR-850	HR-850	Escarpment	Quarry 1	Large solitary corals and stromatoporoids in dark matrix						JB
HR-851	HR-851	Escarpment	Quarry 1	Large solitary corals and stromatoporoids in dark matrix						JB
HR-852	HR-852	Escarpment	Quarry 1	Large solitary corals and stromatoporoids in dark matrix						JB
HR-853	HR-853	Escarpment	Twin Fall Creek	Argillaceous wackestone with brachiopods and crinoids		X				JB
HR-854	HR-854	Escarpment	Twin Falls Creek	Argillaceous wackestone						JB
HR-855	HR-855	Escarpment	Twin Falls Creek	Argillaceous wackestone						JB
HR-856	HR-856	Escarpment	Twin Falls Creek	Argillaceous wackestone						JB
HR-857	HR-857	Escarpment	Twin Falls Creek	Argillaceous wackestone						JB
HR-858	HR-858	Escarpment	Twin Falls Creek	Argillaceous wackestone						JB
HR-859	HR-859	Escarpment	Twin Falls Creek	Argillaceous wackestone						JB
HR-860	HR-860	Escarpment	Twin Falls Creek	Argillaceous wackestone	X	X				JB
HR-861	HR-861	Alexandra	Twin Falls Creek	Coral, stromatoporoid floatstones		X				JB
HR-862	HR-862	Alexandra	Twin Falls Creek	Coral, stromatoporoid floatstones		X				JB
HR-863	HR-863	Alexandra	Twin Falls Creek	Coral, stromatoporoid floatstones		X				JB
HR-864	HR-864	Alexandra	Twin Falls Creek	Coral, stromatoporoid floatstones		X				JB
HR-865	HR-865	Alexandra	Twin Falls Creek	*Amphipora* floatstone to rudstone		X				JB

NO.	OLD NO.	FORMATION	LOCATION	DESCRIPTION	TS	PS	AP	SEM	ISO	THESIS
HR-866	HR866	Aleaandra	Twin Falls Creek	*Amphipora* floatstone to rudstone						
HR-867	HR-867	Alexandra	Twin Falls Creek	*Amphipora* floatstone to rudstone		X				JB
HR-868	HR-868	Alexandra	Twin Falls Creek	Tabular stromatoporoid framestone		X				JB
HR-869	HR-869	Escarpment	Twin Falls Creek	Dolomitic/calcareous siltstone		X				JB
HR-870	HR-870	Alexandra	Surface Outcrop	Tabular stromatoporoids framestone		X				JB
HR-871	HR-871	Alexandra	Surface Outcrop	Tabular stromatoporoids framestone	X	X				JB
HR-872	HR-872	Alexandra	Surface Outcrop	Tabular stromatoporoids framestone						JB
HR-873	HR-873	Alexandra	Surface Outcrop	Tabular stromatoporoids framestone						JB
HR-874	HR-874	Alexandra	Surface Outcrop	Tabular stromatoporoids framestone						JB
HR-875	HR-875	Alexandra	Surface Outcrop	Tabular stromatoporoids framestone						JB
HR-876	HR-876	Escarpment	Dry Creek	Dolomitic/calcareous siltstone						JB
HR-877	HR-877	Alexandra	Dry Creek	Stromatoporoid-coral framestone with dark matrix		X				JB
HR-878	HR-878	Alexandra	Dry Creek	Stromatoporoid-coral framestone with dark matrix		X				JB
HR-879	HR-879	Alexandra	Dry Creek	Stromatoporoid-coral framestone with dark matrix	X	X				JB
HR-880	HR-880	Alexandra	McNally Creek	Stromatoporoid-coral framestone with dark matrix		X				JB
HR-881	HR-881	Alexandra	McNally Creek	Tabular stromatoporoid framestone						JB
HR-882	HR-882	Alexandra	McNally Creek	Tabular stromatoporoid framestone		X				JB
HR-883	HR-883	Alexandra	McNally Creek	Tabular stromatoporoid framestone		X				JB
HR-884	HR-884	Alexandra	McNally Creek	Tabular stromatoporoid framestone		X				JB
HR-885	HR-885	Alexandra	McNally Creek	Tabular stromatoporoid framestone		X				JB
HR-886	HR-886	Alexandra	Alexandra Falls	Stromatoporoid, coral floatstone to Framestone						JB
HR-887	HR-887	Alexandra	Alexandra Falls	Stromatoporoid, coral floatstone to Framestone		X				JB
HR-888	HR-888	Alexandra	Alexandra Falls	Stromatoporoid, coral floatstone to Framestone		X				JB
HR-889	HR-889	Alexandra	Alexandra Falls	Stromatoporoid, coral floatstone to Framestone		X				JB
HR-890	HR-890	Alexandra	Alexandra Falls	Stromatoporoid, coral floatstone to Framestone						JB
HR-891	HR-891	Alexandra	Alexandra Falls	Stromatoporoid, coral floatstone to Framestone	X					JB
HR-892	HR-892	Alexandra	Alexandra Falls	*Amphipora* floatstone to rudstone						JB
HR-893	HR-893	Alexandra	Alexandra Falls	Laminated mudstone	X	X				JB
HR-894	HR-894	Alexandra	Alexandra Falls	*Amphipora* floatstone to rudstone		X				JB
HR-895	HR-895	Alexandra	Alexandra Falls	*Amphipora* floatstone to rudstone						JB
HR-896	HR-896	Alexandra	Alexandra Falls	Green shale						JB
HR-897	HR-897	Alexandra	Alexandra Falls	Laminated mudstone		X				JB